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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

FINAL REPORT

OF THE

DELTA 85 ANOMALY REVIEW COMMITTEE

A.E. JONES, CHAIRMAN

DECEMBER 1, 1971

[redacted]

Glossary of Terms

1. Names:

AGE	Aerospace Ground Equipment
ALRC	Aerojet Liquid Rocket Company
ARIA	Atlantic Range Instrumented Aircraft
BIOS-B	Biological Satellite
BTL	Bell Telephone Laboratories
CDR	Command Destruct Receiver
DIGS	Digital Inertial Guidance System
ETR	Eastern Test Range
FABU	Fuel Additive Blender Unit
FARR	Failure Analysis Report Request
GAS	Gimbal Actuation System
GSE	Ground Service Equipment
GSFC	Goddard Space Flight Center
ITOS	Improved Tiros Operational Satellite
KSC	John F. Kennedy Space Center
MDAC	McDonnell Douglas Astronautics Company
MSFC	Geo. C. Marshall Space Flight Center
OSO	Orbiting Solar Observatory
TC	Thrust Chamber
TETR	Test and Training Satellite
TPS	Thrust Chamber Pressure Switch
ULO	Unmanned Launch Operations (KSC)
VCS	Velocity Cut-off System
WECO	Western Electric Company
WTR	Western Test Range

2. Terminology:

amps	amperes
AOS	acquisition of signal
cc	cubic centimeters
cm	centimeters
cps	cycles per second
dc	direct current
deg/sec	degrees per second
E	voltage
EDT	Eastern Daylight Time
^{o}F	Degrees Fahrenheit
ft lbs	foot pounds
GN_2	gaseous nitrogen
lbf	pounds force
LOS	loss of signal
M	moment
MECO	Main Engine Cutoff (First Stage)
mm	millimeters
mm Hg	millimeters of mercury
ms	milliseconds
NPSH	net positive suction head
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gage
PLD	payload
P/N	part number
Q	Quarter
QD	quick disconnect
RF	radio frequency
RMS	root mean square
RPM	revolutions per minute
sec	second
SECO #1	Stage II engine cutoff-(First burn)
SECO #2	Stage II engine cutoff-(Second burn)
S/N	serial number
T/M	telemetry
T+O	time at launch vehicle lift-off
vdc	volts direct current
VOS	vertical on stand (vehicle erection)

3. Symbols:

θ or θ_p	Angle-pitch (degrees)
$\dot{\theta}$ or $\dot{\theta}_p$	Angular velocity-pitch (degrees/second)
ψ_y	Angle-yaw (degrees)
$\dot{\psi}_y$	Angular velocity-yaw (degrees/second)
δ_p	Engine deflection-pitch (degrees)
δ_y	Engine deflection-yaw (degrees)
Δ	Difference or increment
$\Delta\theta$	Pitch attitude error (degrees)
$\Delta\psi$	Yaw attitude error (degrees)
$\Delta\phi$	Roll attitude error (degrees)
$\dot{H}$	Roll moment (foot pound seconds)
$\ell_t \theta^2$	Tangential acceleration at a point due to pitch angular acceleration
Δp	Pressure increment
Δt	Time increment

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APPENDICES

1. SUMMARY

1.1 DELTA 85 FLIGHT ANOMALY

Delta 85, a two-stage vehicle carrying OSO-H and a secondary payload (TETR-D), was launched from ETR on September 29, 1971, at 0545 EDT. All vehicle systems operated normally through injection into transfer orbit by the second stage. At approximately T+1701 seconds, the second-stage engine was restarted to place OSO-H into the desired 300 n.mi. circular orbit. It was immediately apparent that the second stage attitude control system was unable to maintain the proper vehicle heading during the second burn. The pitch & yaw position gyros were almost immediately driven against their stops and the vehicle began an end-over-end tumbling mode during the second burn. Second burn duration was longer than planned since the centrifugal acceleration produced by vehicle tumbling provided erroneous information to the gyro accelerometers in the velocity cut-off system; the second burn was terminated by propellant depletion (TPS shutdown). Fortunately, a useable orbit was achieved in spite of this anomalous behavior, and the OSO-H spacecraft was stabilized and brought under control following separation from the tumbling second stage (Table 1-1).

TABLE 1-1 Actual vs. Planned Orbits, OSO-H

	Actual	Planned
Apogee, n.mi.	311	300
Perigee, n.mi.	178	300
Inclination, degrees	33.123	32.96

A review of the flight data shows that vehicle performance was nominal up to T+780 seconds, or 185 seconds after second stage engine first burn cutoff (SECO I). At this time, a rapid decay commenced in second stage hydraulic system pressure, which is normally maintained at about 50 psig (when the hydraulic pump is not operating) by a nitrogen gas pressure driven piston in the hydraulic reservoir (see Section 3.1 and Figure 3-1). Vehicle telemetry indicates that hydraulic system pressure had dropped to nearly zero psia by the time the hydraulic pump was turned on at T+1654, in preparation for restart; at pump turn-on the hydraulic pressure did not rise to the 1000 psi level normally required for engine gimbal control. Consequently, when the second stage engine was restarted at T+1701 seconds, the hydraulic system failed to control the second stage thrust vector, resulting in an uncontrolled vehicle tumble. Flight and ground test data indicate that the hydraulic pump did indeed operate, but would not pump immediately due to lack of sufficient hydraulic pressure at the pump inlet.

1.2 ANOMALY INVESTIGATION

In response to Headquarters and GSFC management requests (Appendix A), an Anomaly Review Committee was established (Appendix B) on October 1, 1971 to investigate the Delta 85 vehicle anomaly; to provide an interim report on the cause, and on any related factors pertinent to the launch readiness of Delta 86; and to provide a final report on the cause of the anomaly, including recommendations to prevent recurrence of the problem. An interim oral report was presented to the Director, GSFC, on October 15, 1971; the unanimous conclusion of the Committee was that loss of second stage attitude control during the second burn was caused by loss of precharge nitrogen gas in the hydraulic reservoir. The interim report also included a recommendation to proceed with Delta 86 launch operations, provided that certain corrective actions were implemented on Delta 86 to minimize the likelihood of precharge nitrogen gas leakage (Section 5).

Subsequent to the interim report, additional data from special tests, earlier Delta launches, and Delta 85 ground test and flight records were analyzed by the Committee. Attempts were made to force-fit other possible causes of hydraulic pressure loss into the total sequence of available flight data; no logical physical mechanism of failure was found which could satisfy all of the flight data (Section 2). As a consequence of these analyses, the Committee still unanimously concludes that loss of precharge nitrogen gas caused the Delta 85 flight anomaly (Section 4).

This final report is submitted in accordance with the charter of the Delta 85 Anomaly Review Committee (Appendix A). A Delta 85 investigation chronology is shown in Table 1-2.

Although the pertinent flight data was not reviewed by the Committee, it has been reported that Delta 86 second stage hydraulic system performance was normal, and that it was not a contributing factor in the Delta 86 failure.

TABLE 1-2 Delta 85 Investigation Chronology

Delta 85 Launch	Sept. 29, 1971
KSC Impounded Blockhouse, Gantry, Launcher, and Records	Sept. 29, 1971 (T+2 Hrs.)
Anomaly Review Committee Established	Oct. 1, 1971
Committee Briefings:	
By Delta Project at GSFC	Oct. 5, 1971
By MDAC* at Huntington Beach, Cal.	Oct. 6-8, 1971
Committee Released Blockhouse, Launcher and Gantry (except for 2nd Stage hydraulic fill and bleed cart)	Oct. 12, 1971
Interim Oral Report to Director, GSFC	Oct. 15, 1971
Final Report, Draft	Nov. 18, 1971

*McDonnell Douglas Astronautics Company

2. FLIGHT DATA REVIEW

2.1 FLIGHT RECORDS

Delta 85 telemetry data was recorded from prior to launch through loss of signal following the second orbital pass over Tananarive, as shown in Appendix C. The actual and planned sequences of flight events are provided in Appendix D. A sketch showing expected and actual second stage hydraulic system pressure-time profiles is shown in Figure 2-1; the significant events are discussed below.

2.1.1 Data Prior to Lift-off

Prior to second stage hydraulic system turn-on, hydraulic pressure indicates a normal precharge level of about 50 psig (Figure 2-2).

Approximately 176.7 seconds prior to lift-off, the second stage hydraulic system was turned on in preparation for flight. The turn-on was normal with pressure reaching the accumulator precharge level almost instantaneously and then taking 1.1 seconds to reach the operating value, during which time the accumulator was being filled with hydraulic fluid from the reservoir. In Figure 2-2, the system pressure indications have been adjusted to account for loading of the telemetry channel imposed by a ground monitor circuit; Figure 2-3 shows the voltage increase (equivalent to 20 psi) that occurs when the ground monitor circuit is disconnected on umbilical separation.

2.1.2 Lift-off Through Transfer Orbit Injection (SECO-I)

Through first stage powered flight and the first burn of the second stage, hydraulic pressures remained stable, as expected (Figure 2-1).

At SECO-I the hydraulic pump was turned off and the system bled down to the accumulator precharge pressure in 5.5 seconds (Figure 2-4). The bleeddown trace compares closely to those noted on numerous other Delta missions.

2.1.3 Transfer Orbit - Second Stage Coast Phase

The system pressure was 65 psig immediately following post-SECO-I bleeddown (Figure 2-4). Thereafter, pressure decayed at a slow, steady rate until T+780 seconds at which time the pressure was 53 psig (Figure 2-5).

From T+780 seconds to T+970 seconds, the pressure decayed significantly at what appears to be an exponential rate. At T+970 seconds the transducer indicated nearly zero psia, and remained at that level until T+1705 seconds. Figure 2-5 provides an amplified replay of telemetry data obtained during most of this pressure decay period.

At T+1654.6 seconds the hydraulic motor pump was turned on in preparation for restart; hydraulic pressure failed to respond (Figure 2-1). At pump turn-on, the engine battery voltage telemetry trace indicated the introduction of approximately a 20 amp electrical load. With a properly functioning hydraulic system, this load should have been about 35 amps.

2.1.4 Second Stage Restart Through SECO-II

Engine restart occurred as programmed, at T+1701.6 seconds. Approximately one second after engine start, the engine began slewing pitch up, yaw right (Figure 2-6).

At T+1705.5 seconds, as the engine was reaching its stops in both pitch and yaw, hydraulic system pressure suddenly increased to about -5 psig (10 psia). At T+1707.2 the engine began slewing yaw left at a relatively slow rate. At T+1709 the slew rate increased substantially. At T+1711.5 seconds, the pressure again experienced a sudden increase, this time to about 28 psig.

At T+1714 seconds the yaw actuator slewed suddenly (at approximately 1.8 degrees per second), followed 0.2 seconds later by a rapid increase in hydraulic system pressure, reaching the accumulator precharge level (670 psig) in 0.8 seconds. The pressure continued to rise at a slow rate, eventually reaching 875 psig at T+1716.6 seconds. At that time, the pump was turned off concurrently with SECO-II. The system then bled down to 645 psig in 1.75 seconds and then decayed to an indicated zero psia within 2.5 seconds. At this point, the vehicle was tumbling in pitch and yaw at a rate of 320 degrees per second.

As shown in Figure 2-1, second stage hydraulic system pressure should have been approximately 1000 psi at the time of second stage ignition, and should have begun its characteristic shutdown decay with SECO-II, at about T+1708 seconds.

2.1.5 Second Pass Over Tananarive

Vehicle telemetry was monitored during the second pass over Tananarive from T+8251 to T+8889 seconds; at T+8253 seconds the hydraulic system was operating at a pressure of 710 psig, but decreasing at a rapid rate (Figure 2-7). At approximately

T+8273 seconds the accumulator piston bottomed, as evidenced by the sudden 40 psi drop. The pressure then continued to decay until approximately T+8358 seconds, at which time the hydraulic pressure dropped suddenly to zero; engine battery voltage showed a step increase at the time the pressure suddenly dropped, indicating that the relay providing power to the hydraulic pump, dropped out. Hydraulic pump operation at this time is not considered anomalous, since it is normal for the hydraulic pump to turn back on sometime subsequent to spacecraft separation; this phenomenon is caused by the switching of relays as engine battery voltage is depleted.

2.2 VALIDITY OF FLIGHT DATA

The hydraulic pressures noted previously are accurate only within the constraints of monitoring equipment and are mostly reliable as trend indications. The telemetry system is considered to provide an absolute accuracy of $\pm 2\%$ of full scale, although a differential accuracy of perhaps $1/2\%$ can be achieved. Additionally, telemetry data is expected to vary to some degree from station to station; however, the data recorded for Delta 85 at the various tracking stations (Appendix C) was found to be in substantial agreement. The hydraulic pressure transducer is accurate within $\pm 2\%$, and can become erratic at pressures below one atmosphere.

The Committee questioned the validity of the low hydraulic pressures shown after T+780 (Figures 2-5 and 2-6) since the range of the pressure transducer is 0 to 2000 psig. The normal operating hydraulic system pressure of 1050 psig corresponds to approximately 52% of full scale telemetry data. The data recorded for the normal precharge pressure was on the order of 6% of full scale.

Comparisons were made between test records, available flight records on several prior Delta missions, and the results of special calibration tests of a spare transducer (see Section 3.3.1), with particular attention being directed to the low end of the pressure scale. As a result of these investigations and an analysis of flight controls system performance, the Committee concluded that the Delta 85 hydraulic pressure transducer functioned normally, and that the pressure decay recorded on telemetry was valid data. However, it was concluded that quantitative data below one atmosphere is questionable.

2.3 HYDRAULIC SYSTEM DATA ANALYSIS

2.3.1 System Performance Up to T+780 Seconds

System pressure prior to turn-on (T -176 seconds) was 15 psi lower than that noted immediately subsequent to SECO-I. This change correlates to that which would be expected as a result of a temperature induced volumetric increase due to operation of the hydraulic pump up to SECO-I. Data obtained during the launch of BIOS-B (Appendix E) indicates that after 13 minutes of flight (which is equivalent to the OSO-H mission), reservoir fluid temperature increased to approximately 174^{o}F. The fluid temperature prior to startup is usually 60 to 70^{o}F. Assuming a similar 100^{o}F temperature rise for Delta 85, calculations indicate that the fluid pressure should increase by approximately 20 psi. Considering telemetry and transducer accuracies, this calculated value corresponds favorably with the telemetry data.

Hydraulic system pressure remained very steady throughout first stage flight and the first burn of the second stage engine. Only a slight pressure decrease was noted, which is not considered anomalous.

The system bleeddown immediately following SECO-I was normal. The slight roundness of the trace near accumulator depletion (see Figure 2-4) has been noted before on numerous missions (BIOS-B, Intelsat II F2, TOS-C, Intelsat III F, and others) and results from a slight amount of air entrainment in the hydraulic system. This entrained air is not considered to be significant to the Delta 85 anomaly.

Between T+600 seconds and T+780 seconds pressure decreased approximately 12 psi (from 65 psig to 53 psig). Based on the BIOS-B flight data, hydraulic reservoir temperature should have decreased approximately 10^{o}F over this 3 minute period. Calculations indicate that this temperature change will only account for a very small decrease in gas charge pressure (approximately 1 psi). Review of previous flight data, however, (Table 2-1) indicates that a 12 psi decrease in system pressure is not abnormal during this period.

The Committee concluded that the performance of the second stage hydraulic system was normal up to T+780 seconds.

TABLE 2-1 POST SECO #1 PRESSURE DECAY HISTORY

Delta Vehicle	Mission	Hydraulic Pressure (4) vs Time After Bleed-Down					
		Initial		Intermediate		At LOS	
		Δt (SEC)	P(PSIG)	Δt (SEC)	P(PSIG)	Δt(SEC)	P(PSIG)
71	INTELSAT-E	1	80	160	50	360	50
72	OSO-6	1	100	(1)	(1)	400+	75
74	SKYNET	1	100	(2)	(2)	20	(2)
75	INTELSAT-F	1	110	(2)	(2)	10	(2)
77	NATO-A	1	110	100	75	400	75
78	INTELSAT-G	1	95	140	72	410	60
79	INTELSAT-H	1	80	100	45	360	45
80	SKYNET	1	100	120	80	380	80
82	NATO-B	1	95	100	55	400	55
83	IMP-I (3)	1	75	140	65	211	65
85	OSO-H (3)	1	80	180	65	360	0

(1) Data not available

(2) Loss of Signal (LOS) occurs immediately after bleed-down

(3) Two-burn mission

(4) Pressure values are taken from NASA-ULO Ground Station records at KSC. Generally, they are consistently higher than like data from the McDonnell-Douglas Delta Ground Station, whose Delta 85 values are utilized in the text. The differences reflect ground station characteristics only.

2.3.2 Performance After T+780 Seconds

The first anomaly in the flight data occurred approximately 180 seconds after SECO-I, at T+780 seconds (see Figures 2-1 and 2-5). A non-linear decay of the hydraulic system pressure began at this point and extended through most of the coast period prior to second stage restart.

The second anomaly in the flight data (at approximately T+1655 seconds) was a failure to build up hydraulic pressure when the pump was turned on 47 seconds prior to second burn ignition. However, as noted previously (Section 2.1.3), telemetry indicated a pump motor voltage response; the magnitude of the battery voltage drop was approximately half that for normal pump operation. The voltage data is consistent with pump cavitation due to lack of precharge pressure at the pump inlet. Normally the nitrogen gas precharge in the hydraulic reservoir provides the NPSH (Net Positive Suction Head) required for proper pump operation.

A cavitation condition was consistently simulated in special hydraulic systems tests (see Section 3.3.2) by reducing the inlet pressure below a threshold of about 10 psia. These tests have also indicated that reliable and normal hydraulic pump starts can be made with an inlet pressure as low as 12 psia. These tests verify that the inlet pressure of Delta 85 was below threshold at the time of pump turn-on prior to second burn.

The third anomaly observed is a logical consequence of no hydraulic system pressure. At initiation of second burn, telemetry data shows the engine moving to limit stops in pitch & yaw. Without hydraulic pressure, the engine actuators are not constrained against movement. A bleed orifice in the actuator piston allows a flow of fluid past the piston, permitting thrust chamber motion about its gimbal when the hydraulic system is off. During engine firing, thrust misalignments and thrust vector variations are expected to cause free engine movement in pitch & yaw in the absence of hydraulic pressure. The expected result would be large transverse thrust components which would produce tumbling about the vehicle center of gravity, and a severe deviation from the desired flight path. Telemetry records indicate that this situation existed on Delta 85, culminating in a tumble rate of approximately 320 degrees/second at SECO-II. The resultant incremental velocity vector difference from the planned flight path caused the anomalous final orbit of Delta 85 (Table 1-1).

After the vehicle started tumbling and just prior to SECO-II, the hydraulic pump (which had been running free in cavitation) began to build up system pressure. The pressure increased slowly at first, leveled off, then rapidly increased to 670 psig (Figure 2-6). The accumulator began filling at 670 psig, and a maximum pressure of 875 psig was reached as SECO-II occurred. Tests have indicated that a cavitating hydraulic pump will respond to pressure or flow spikes (see Section 3.3.2) and begin pressure buildup even if the suction head is below the cavitation threshold. It is considered likely that pressure spikes due to engine actuator motion created a similar situation resulting in eventual hydraulic system pressure buildup. The shape of the pressure buildup and subsequent bleed down traces were approximately normal with some slight deviations which can be attributed to engine dynamic motions, and servo valves responding to error signals.

The hydraulic system pressure decay observed in the Tananarive data on the second pass, is not considered anomalous. The decay rate is consistent with decreasing voltage as the engine battery is being discharged. At signal acquisition Tananarive recorded an engine battery voltage of approximately 12.7 volts, which decreased to about 4.8 volts at which time the relay dropped out, turned the pump off and unloaded the battery, which then rose to 7.4 volts.

2.4 FLIGHT CONTROLS ANALYSIS

2.4.1 Apparent Velocity Control System (VCS) Anomaly

The actual duration of the second burn was 15.1 seconds instead of the planned 6.8 seconds. Second burn termination was planned to be initiated by the VCS but telemetry indicates that the VCS did not initiate SECO-II. An investigation was performed by MDAC to explain this apparent anomaly by correlating VCS operation with vehicle motion.

Figure 2-8 defines the location of the VCS along with other pertinent parameters. The integration of engine motion results in the vehicle rates indicated in Figure 2-9. These rates cause a centrifugal acceleration which counteracts the axial acceleration caused by engine thrust. This "negative" acceleration results in a lower VCS output than would be expected during normal operation. Figure 2-10 shows the actual telemetered VCS output along with calculated outputs for second stage thrust levels of 6400 lbf to 6800 lbf. Good correlation between the actual and predicted VCS output is evident, confirming that VCS operation was normal when vehicle motion is considered, and that it should not have issued a SECO command.

2.4.2 Post SECO-II Attitude Control

The disturbing torque causing the vehicle to tumble, terminates at SECO-II. The coast control jets then came on to help control the vehicle until gas depletion at approximately T+1770 seconds. During this interval the total vehicle tumble rate was reduced from approximately 320 deg/sec to 304 deg/sec, accounting for the reduction in axial loads experienced by OSO-H and TETR-D. The vehicle rate then remained constant until OSO-H separation at approximately T+1997 seconds.

2.4.3 Roll Transients During Second Burn

An abnormal roll transient occurred at the onset of second stage restart, which can be attributed to the pitch and yaw deflections of the thrust chamber. As can be seen from Figure 2-11, the transient began as the main engine goes hard-over in the pitch and yaw planes. A roll moment would result if the vehicle roll center of gravity and main engine gimbal points were offset. An offset of approximately 0.07 inches (approximately 3.1 ft-lbs of roll moment for hardover engine) would cause the observed roll motion. This magnitude of off-set is easily within the realm of system tolerances. The roll transient is damped by the roll jets and dies out after the engine is shut down.

2.4.4 Analysis of Engine Motion

An analysis of engine motion was performed by GSFC (Appendix F), which indicates that the pitch and yaw actuator positions before, during and after second burn, are consistent with Delta 85 vehicle dynamics, hydraulic pressures and control logic circuitry.

2.4.5 External Roll Moment After SECO-I

An external roll moment was observed during the period following SECO-I. This roll moment was due to forces transmitted to the second stage by the continuing spin up of the OSO-H sail which was initiated at second stage separation. Figure 2-12 shows the value of the observed moment obtained from flight telemetry along with a comparison of its theoretical value derived by MDAC. Good correlation exists in the region after SECO-I. It can also be seen that the general shape of the curves are the same during second stage burn (250 - 500 seconds) with the theoretical moment approximately -0.1 ft-lb larger than the observed value. This difference during second stage burn can be accounted for by swirling exhaust gases acting on the thrust chamber.

2.5 CONCLUSIONS FROM DATA REVIEW

The results of the flight data review provide conclusive evidence that the OSO-H mission anomaly was caused by failure of the second stage hydraulic system to provide control pressure to the engine actuators. The Committee unanimously concluded that this condition resulted from the loss of precharge pressure on the hydraulic pump inlet, prior to pump activation for the second burn.

3. FAILURE INVESTIGATION

3.1 HYDRAULIC SYSTEM DESCRIPTION

The second stage hydraulic system has flown on over a hundred Ablestar and Delta missions without experiencing major changes. Of these, 8 were second burn missions (including Delta 85). Although the Delta 85 launch vehicle configuration included several first flight items (Appendix G), none were applicable to the hydraulic system. The Delta 85 second stage hydraulic system configuration (Figure 3-1) is identical to those employed in 21 previous Delta flights. Illustrations showing the installation of this system in the second stage, are provided in Appendix H.

The system is normally charged with 36 cubic inches of hydraulic fluid (MIL-H-5606), with 19 cubic inches of this volume contained in the reservoir (system not operating). The accumulator is precharged with nitrogen gas to 650 psig; during operation, the accumulator begins to fill when hydraulic pressure overcomes this precharge load. At a nominal operating pressure of 1050 psig the accumulator contains approximately 4.3 cubic inches of hydraulic fluid, which has been pumped from the reservoir supply. The reservoir is precharged with nitrogen to 50 psig in order to maintain a sufficient margin over pump NPSH (Net Positive Suction Head), thereby preventing cavitation; the precharge also serves to move the reservoir piston to occupy the fluid volume which has been extracted to fill the accumulator. A dip stick is attached to the reservoir piston to verify: that the system is fully charged with hydraulic fluid; that the proper volume of fluid has been extracted to fill the accumulator during system operation; and that air has been bled from the fluid volume to an acceptable level.

When the hydraulic system is turned on, the dip stick moves approximately 7/8 of an inch into the reservoir as the accumulator is charged with fluid from the reservoir. When the system is turned off, bleed down occurs through orifices in the actuators, and the fluid in the accumulator is forced back into the reservoir by the accumulator precharge. On bleed-down the dip stick normally extends beyond its original position to a point corresponding to the volumetric change resulting from increased fluid temperature.

As shown in Figure 3-1, a guard is provided to protect the dip stick from being bent or damaged during handling and after installation. It consists of a flat piece of sheet metal (painted red) wrapped around most of the reservoir cylinder circumference, and is held in place by a single screw type tension clamp. The resultant slot in the cylindrically formed guard facilitates removal of the guard for specific tests and before flight.

3.2 POSSIBLE CAUSES OF FAILURE

Three possible failure modes emerged from a review of the hydraulic system, considering the pump precharge pressure loss and the subsequent vehicle anomalies described in Sections 2.3 and 2.4. These failure modes are: loss of nitrogen precharge pressure in the reservoir; a stuck reservoir piston; or a hydraulic fluid leak.

3.2.1 Loss of Reservoir Nitrogen Precharge Pressure

3.2.1.1 Agreement with Flight and Special Test Data

A gas leak would account for the sudden non-linear pressure decay following SECO-I. Resultant relaxation of the fluid precharge load on the piston would produce the recorded pressure trace. Some fluid pressure can remain because of the vapor pressure of the fluid and due to some air entrapped and in solution with the oil. This residual gas pressure on the fluid side, however, is quite small, and is not expected to be measurable with the transducer employed in the hydraulic system. Thermal contraction of the hydraulic fluid would ultimately reduce the system pressure to near zero psia. With no force available to move it toward the fluid, the piston would essentially be stuck by virtue of piston O-ring friction.

Special tests conducted at ALRC (see Section 3.3.2) confirmed that reservoir precharge pressures below 9 psia consistently resulted in pump cavitation; test data closely approximated Delta 85 telemetry, except for a slow pressure buildup, in simulations of second burn ignition conditions. This difference is believed to be the result of air leakage past the pump seal (pump was not exposed to vacuum) as well as lack of the inlet pressure head which Delta 85 experienced due to vehicle tumble.

The bleed-down following SECO-II (Figure 2-6) would also result from near zero precharge pressure. The rapid but not instantaneous drop to zero, can occur due to thermal contraction effects as the hydraulic fluid temperature drops.

The hydraulic pressure trace recorded by Tananarive on the second pass is not inconsistent with this failure mode. The pressure head on the pump inlet due to vehicle tumble provides an additional margin over the pump starting conditions experienced early in the second burn.

The Committee unanimously concluded that this failure mode is consistent with all of the flight data.

3.2.1.2 Leak Sources

An analysis of the pressure decay rate commencing at T + 780 seconds indicates that the leak rate corresponds to an equivalent orifice of approximately .006 inch diameter, or roughly the size of a small grain of sand. As shown in Figure 3-2, gas leakage is possible past the static o-ring seal on the end cap of the reservoir, past the dynamic o-ring seal surrounding the dip stick, and out the fill port through the nitrogen precharge valve (Figure 3-3). Leakage past the piston o-ring which seals the fluid/gas interface is not suspect since it would not correlate with observed data.

End Cap Static O-ring

The leakage path between the end cap and the reservoir cylinder is sealed by a single o-ring (Figure 3-2). No data was found which could explain why this seal should fail; it is a static seal with no significant history of leakage problems. The conditions that this seal did not experience in ground tests prior to launch are related to the space environment.

Although the Committee does not believe that leakage occured past this seal, leakage is possible merely because the o-ring provides a single seal.

Nitrogen Precharge Valve and Port

The Schrader valve is used for loading and venting nitrogen precharge pressure during ground tests and prior to launch. The valve is lockwired to the end cap, and the interface is conventionally sealed with a single (static) o-ring. If any leakage occurs past the metal-to-metal seat, the gas would also have to leak past the pressure cap, or the (dynamic) o-ring surrounding the poppet, in order to vent outside. The dynamic o-ring seal acts as a static seal during flight. The likelihood of leakage past the valve seat causing the loss of precharge gas is considered remote due to the dual seal design.

Past history with this component does not provide any particular basis for suspecting this as the leak source. As with the end cap static o-ring, the possibility of leakage is inherent simply because the indicated seals exist.

Dip Stick O-ring

Figure 3-2 shows the single o-ring between the end cap and the dip stick. As noted in Section 3.1, system activation causes the dip stick to travel 7/8 inch into the reservoir, and back out again by a slightly greater amount on system shutdown. The single dip stick o-ring provides the dynamic seal which is required to prevent gas leakage before, during and after such sliding motion. This seal is immediately suspect merely because it is the only operating dynamic seal in the nitrogen pressure envelope.

Significant information was uncovered during the Committee's investigation, which cast doubt upon the integrity of this seal, as follows:

- There are no provisions for lubricating the dip stick seal beyond the supplier's lubrication with hydraulic fluid at the time the reservoir is first assembled. The assembly date for the Delta 85 reservoir was 4/9/69; the o-ring was not lubricated again prior to launch, and was probably dry during ETR checkout.

- The hydraulic system frequently reaches 180^{o}F during tests. At this temperature the vapor pressure of Mil-H-5606 could be as high as 4 mm Hg (Ref. Appendix I). This would indicate that the lubricat on on the o-ring would have evaporated quickly on the exterior side of the seal. Bubble checking the reservoir with soap solution after pneumatic charging, as called out in the checkout procedures, also contributes to removal of the initial lubrication, thereby increasing the possibility of a dry seal.

- Other than normal handling and cleanliness practices, there are no provisions for protecting the seal from external contamination such as sand, dirt, metal chips, etc. When the vehicle is erected at ETR, the exposed seal is facing upward, in an optimum position to collect contaminants on or near the seal.

- The o-ring retaining slot (Figure 3-4) in the end cap is difficult to machine; accurate dimensional and quality inspection is equally difficult.

- Inspection of the o-ring for damage, after installation of the reservoir on the second stage, is extremely difficult.

- The dip stick seal does not receive adequate attention in terms of test and inspection procedures beyond the hydraulic reservoir assembly stage.

- The aluminum dip stick can be easily damaged by nicks, scratches or bending during and following removal of the sheet metal guard.

- A special Committee investigation (summarized in Appendix I) of a dip stick o-ring from an old display model reservoir, uncovered evidence of possible abrasion damage due to friction rolling of a non-lubricated o-ring, induced by dip stick motion; the rolling action of the o-ring could introduce contaminant particles into the seal.

- Assembly and checkout of the Delta second stage is accomplished in a horizontal position prior to shipment to the launch site; it is vertical for the first time on the launch pad. Although the interior is vacuumed during assembly it is not likely that all metal chips and fragments have been removed. There is a good possibility that these particles fall from interior crevaces, from the time the vehicle is erected through first and second stage engine firings.

- The reservoir and accumulator each received their final nitrogen precharge at ETR on 8/11/71, 49 days prior to launch; the G.S.E. pressure gage and the pressure transducer telemetry output were not checked against each other at the time. These pressures were monitored, using the hydraulic pressure transducer, throughout pre-launch testing. No significant changes in precharge pressures were noted. It is expected that a total pressure loss (at sea level) would be detected although this would correspond to only 2 - 3% of full scale on telemetry.

- The Delta 85 second stage hydraulic system experienced an unusually high number of pre-launch on-off test cycles and total system operating time (10-3/4 hours), as a consequence of supporting special tests to resolve a VCS checkout anomaly (Appendix J); normally, total operating time is in the range of 4-7 hours. The increase in testing due to the VCS problem was 4½ hours running time and 50 turn-ons.

- Dip stick motion due to fluid thermal contraction from immediately after SECO-I, to the time the anomaly occurred, is estimated to have been 1/16 inch.

On the basis of these findings the Committee concluded that the Delta 85 dip stick o-ring was not lubricated, and that this condition can result in abrasion damage due to rolling caused by dip stick motion each time the system is turned on and turned off. Furthermore, this rolling action, which occurred an abnormally high number of times on Delta 85, can also provide a means for introducing contaminant particles between the o-ring and the dip stick. In either case, resultant damage to the o-ring or the presence of a contaminant could be sufficient to cause gas leakage.

3.2.2 <u>Stuck Reservoir Piston</u>

3.2.2.1 Agreement with Flight and Special Test Data

All vehicle anomalies noted subsequent to the initial pressure decay anomaly, are consistent with a postulated stuck piston. In fact, the same explanation provided for the gas leak failure mode applies to the stuck piston theory during this time interval; this is true since piston friction effectively creates a stuck piston if precharge nitrogen gas is depleted.

The only valid data for differentiating between the two failure modes is that surrounding the initial pressure decay. The sudden drop in system pressure noted at T + 780 seconds could not occur unless the piston was abruptly and firmly jammed.

3.2.2.2 Possible Failure Mechanisms

No logical physical mechanism was found which would explain an abrupt, firm jamming of the piston. If a bent dip stick is postulated, a pressure trace approximating the actual data could result. However, a smoother drop in system pressure would be experienced due to the elasticity of the configuration. Consequently it is not believed that a bent dip stick could produce the sudden pressure decay experienced. A sudden jamming of the piston by the introduction of a foreign particle between the piston and reservoir cylinder is also considered unlikely due to expected elasticity effects.

3.2.3 <u>Hydraulic Leak</u>

3.2.3.1 Agreement with Flight and Special Test Data

A hydraulic fluid leak from either the pressure or return side of the system would cause the pressure decay noted subsequent to SECO I. Pressure would decrease concurrently with movement of the reservoir piston which would allow the nitrogen precharge to expand. Almost all of the oil would have had to be withdrawn from the reservoir to duplicate the pressure drop recorded.

On the other hand, a substantial amount of oil would have to remain in the system in order to allow the pressure buildup seen toward the end of the second burn, as well as during the second pass over Tananarive. Accordingly, if there was a leak, only a small amount of oil was lost and the leak either subsided to a negligible amount or stopped altogether.

Leakage of hydraulic oil from the high pressure side of the system is unlikely because of the normal bleeddown noted after SECO II. Its short duration (1.8 seconds as opposed to 5 seconds nominal) is due to failure of the system to reach operating pressure as well as due to the fluid demand from actuator motion taking place at that time.

Pressure decay due to a hydraulic leak subsequent to SECO I would be expected to be linear up to a point corresponding to reservoir o-ring drag. Subsequently there would be an abrupt drop to 0 psig in a similar manner to that seen during a normal accumulator bleeddown. Although it might be difficult to see on telemetry (less than 1% of full scale) there is no evidence that such a drop occurred.

Special tests conducted at ALRC showed that hydraulic system pressure could not rise above 750 psig with the reservoir fluid depleted; during second burn, a peak pressure of 875 psig was attained, indicating that fluid was in the reservoir.

On the basis of these considerations, the Committee concluded that the data does not substantiate a hydraulic leak as the cause of the flight anomaly.

3.3 SPECIAL TESTS

3.3.1 Hydraulic Pressure Transducer

Special calibration tests conducted at GSFC on an identical hydraulic pressure transducer indicate that this component is very stable and linear, has excellent repeatability, and is apparently temperature compensated; however, its readings are questionable below a pressure of one atmosphere. The results of these tests are summarized in Appendix K. MDAC also conducted special transducer tests, and reached the same conclusions.

3.3.2 Tests at ALRC

A series of tests were performed at Aerojet Liquid Rocket Company (ALRC), Sacramento, in an attempt to reproduce the possible failure modes.

These tests were performed utilizing the Gimbal Actuation System (GAS) simulator depicted in Figure 3-5. This simulator consists of a vertically mounted engine bell, two servo actuators, and a hydraulic accessory unit containing reservoir, accumulator, high pressure relief valve, filters, motor/pump assembly, and associated tubing mounted in flight configuration. During the testing a P/N 097-017-1 reservoir was used instead of a P/N 097017-3 unit as had flown on Delta 85. The difference between the two configurations is that the latter has a shoulder on the outside of the reservoir barrel to provide additional strength at the point where the supporting strap is installed. Also, two different types of servo actuators were utilized. Initially P/N 096320-9 units were used, which are the actuators employed in Titan Transtage Vehicles and which will be used with the AJ10-118F second stage of the Delta (DIGS) launch vehicle; this actuator does not have an orifice across the piston.

As the testing progressed, however, -5 configuration units (with orifices) as used on the AJ10-118E second stage which flew on Delta 85, were installed to more closely simulate the Delta 85 hydraulic system.

Other equipment used during testing included a vacuum pump to provide negative pressures at the reservoir precharge nitrogen chamber, a dip stick position transducer, a reservoir oil pressure transducer, and a Sanborn Recorder.

In attempting to duplicate the failure mode, a total of 32 test runs were performed. Each of these runs consisted of setting the system up in such a fashion as to simulate any of the three possible failure modes. A summary of these tests is provided in Appendix L.

3.4 RELATED DATA

Delta 85 and general histories of the second stage hydraulic system are provided in Appendix M.

4. CONCLUSIONS

There is a very remote possibility that a stuck reservoir piston could have caused the failure since a firmly jammed piston at T+780 seconds would have produced identical flight data. The Committee judged this failure mode to be extremely improbable.

In spite of the above, the Anomaly Review Committee unanimously concluded that the initiating cause of the OSO-H mission anomaly, was loss of precharge nitrogen gas from the second stage hydraulic system reservoir.

5. CORRECTIVE ACTIONS TAKEN ON DELTA 86

Actions were placed on the Delta Project to provide redundant gas seals in the reservoir as a precondition to the launch of Delta 86. The modified configuration (design concept) derived by the Project (Figure 5-1) was approved by the Anomaly Review Committee prior to implementation. The reworked reservoir (with new end cap) was requalified by proof pressure and vibration tests prior to Delta 86 launch. A requirement to measure dip stick rod concentricity, and perpendicularity with respect to the piston, was also placed on Delta 86.

Additionally, launch site test procedures were revised to assure that:

- The dip stick would not be damaged by removal and installation of the sheet metal dip stick guard and the new cover encompassing the redundant o-ring.
- All hydraulic system seals, including the dip stick and Schrader valve, are leak checked before and after installation of backup seals/covers.
- The dip stick and Schrader valve covers are lock-wired, and that the dip stick o-ring is lubricated, as prerequisites to launch.
- The hydraulic system pressure indication on telemetry is calibrated, by checking at one atmosphere and at 50 psig (as supplied and verified by appropriate G.S.E.).

6. RECOMMENDATIONS

A major concern which became apparent to the Committee, and which affects not only the second stage hydraulic system but the entire Delta vehicle above the first stage, is the adequacy of Delta qualification for two-burn missions. In two-burn missions, as well as in coasting flight prior to third stage spin-up and separation, the second stage is required to perform in a space environment for extended periods of time. In such instances the vehicle must function as a spacecraft although it has not been tested as a spacecraft. The question of whether it should be treated more like a spacecraft is not considered to be within the scope of this Committee's charter; however, the Committee recommends that GSFC review this as soon as possible. This matter should be addressed separate from this Committee's activity since it involves an assessment of the purpose of the Delta launch vehicle with respect to trade-offs of cost and reliability and its relation to other launch vehicles. For example, should Delta be reserved for those missions where cost effectiveness is important and the spacecraft is comparable in cost to the launch vehicle, or should Delta be upgraded in reliability because its more expensive payloads demand a lower risk? It is probable that it cannot be both low cost and highly reliable at the same time.

With respect to the second stage hydraulic system, which caused the Delta 85 anomaly, several modifications are required to assure non-recurrence of the Delta 85 anomaly. The following recommendations should be implemented on all future Delta second stages, beginning with Delta 87:

1. Incorporate fully redundant external seals in the pneumatic side of the reservoir.

2. Incorporate a transducer to indicate reservoir piston position on telemetry. Effectivity of this recommended change need not be Delta 87, but as soon as practical considering that immediate action is taken to implement this item.

3. Review and re-write, as required, all hydraulic system test procedures:

    - Specify precisely what leakages are allowable.

    - Wherever practical, compare G.S.E. and telemetry readouts.

    - Until a reservoir piston position readout is available, the nitrogen precharge pressure should be verified as close to launch as practicable.

- Lubricate the dip stick O-ring (if the dip stick is retained) with DuPont Krytox 143AZ or an equivalent lubricant, and provide a cover to protect the rod from damage and protect the O-ring from contaminants. Once the position transducer is incorporated (item 2 above) the cap should not be removed, except in extenuating circumstances.

4. MDAC and ALRC documentation should be reviewed for consistency and definition of specification values. Some instances were found where ALRC specification values are not defined, and where some are inconsistent with MDAC documentation.

Assuming that the above recommendations are implemented, the Committee believes that the Delta second stage hydraulic system can be depended upon, with a reasonable degree of certainty, to provide reliable operation. In the event that a general reliability upgrading results from the recommended programmatic review, the following items should be considered, with respect to the hydraulic system:

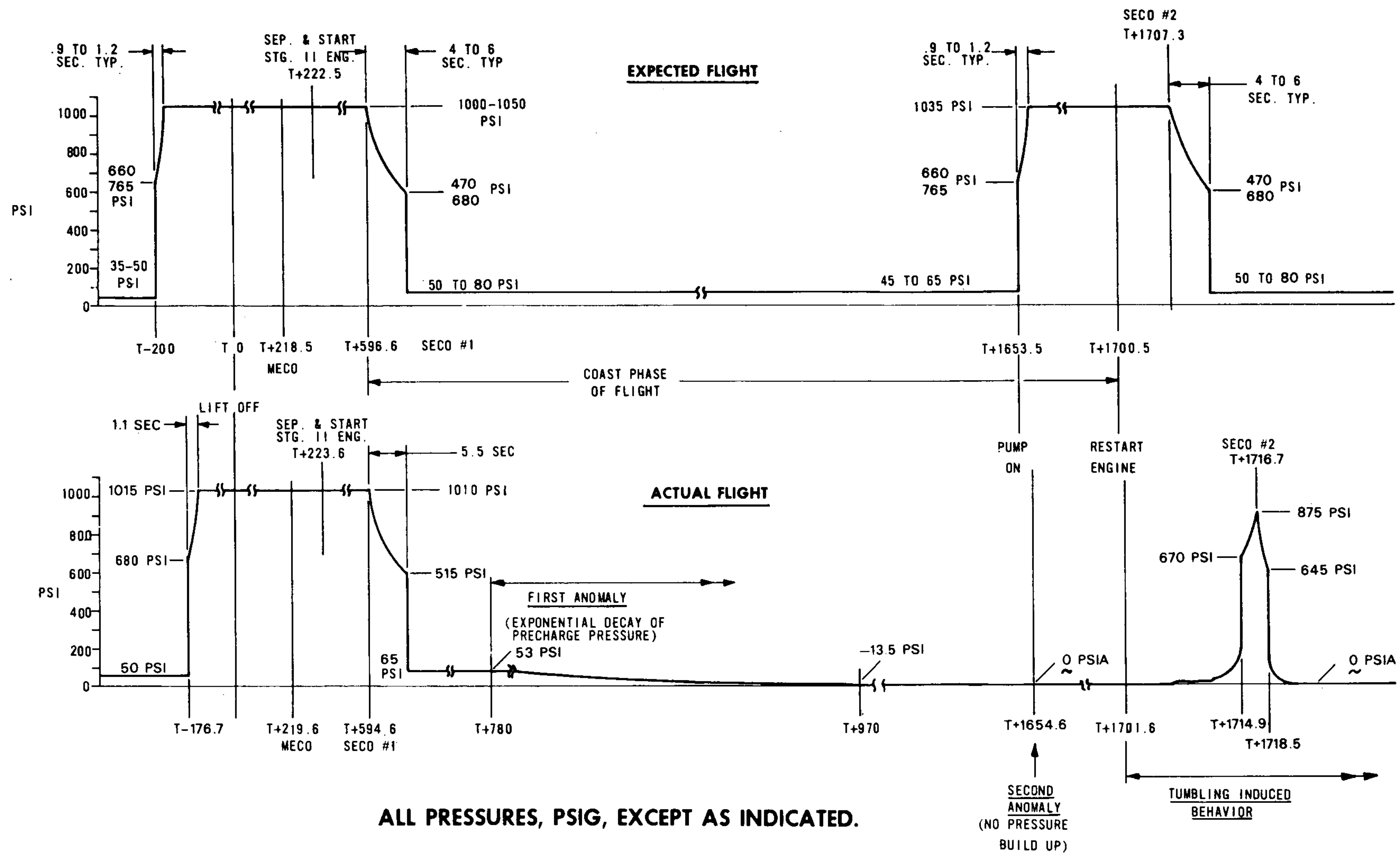
- Some additional reliability may be obtained by incorporating an integral reservoir/accumulator unit, thereby avoiding the use of separate components with interconnecting tubing. One system that might be adopted without major redesign is currently being used on Minuteman; another approach, currently used on Thor, Saturn and Titan, would require major redesign for Delta application.

- Consideration should be given to use of a pump which does not require as much positive inlet pressure for proper performance.

- If the present distributed system is retained, then considerable upgrading could be accomplished by the use of MC fittings and stainless tubing in place of the present AN aluminum hardware, to minimize susceptability to vibration induced leaks. Consideration should also be given to the use of hydraulic bleed valves (rather than cracking fittings) to remove air from the system. Strictly enforced acceptance tests and procedures could be implemented for servo valves, O-rings, relief valves, filters, charging valves, pumps, reservoirs and accumulators.

In any major redesign a prime consideration should be to provide a system which could be shipped from the factory in a "ready to operate" condition. Elimination of field charging, bleeding, and other servicing (requiring personnel working adjacent to other critical vehicle components) should be a reliability advantage which would have implications beyond just the hydraulic system.

During the course of its investigation, the Committee found out that the ETR (Range) tracking aircraft, and tracking stations at Ascension and Antigua had shut down (as planned) after their first pass was completed. This prevented the acquisition of potentially important data prior to the second pass acquisition by Tananarive. Although this matter is not directly related to the Delta 85 anomaly, the Committee recommends that the Delta Project review and revise (if necessary) their SIRD to assure that all appropriate tracking stations are kept active in emergency situations.



ALL PRESSURES, PSIG, EXCEPT AS INDICATED.

FIGURE 2-1, SECOND STAGE HYDRAULIC SYSTEM PRESSURE PROFILES, DELTA 85

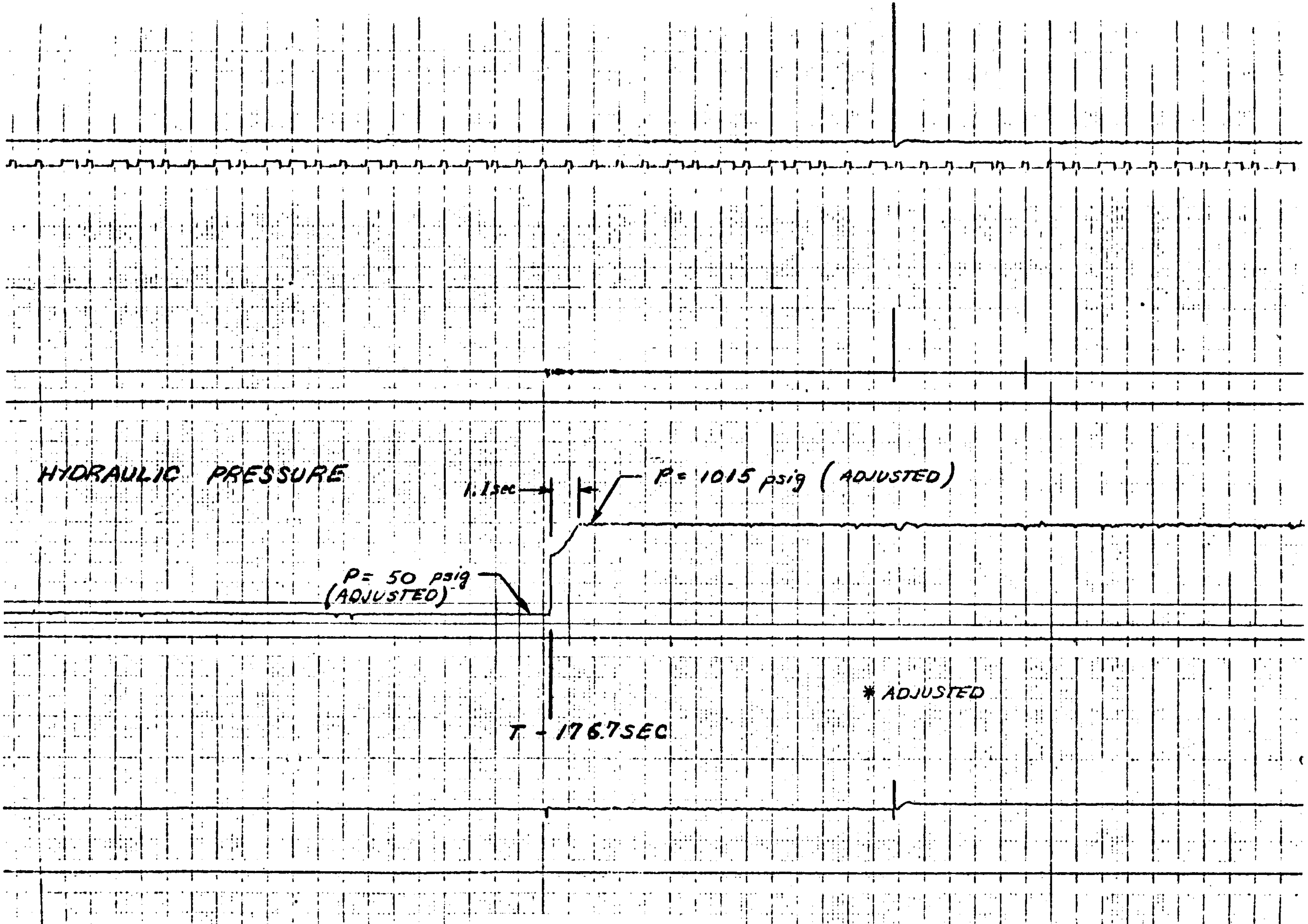


FIGURE 2-2, SYSTEM TURN-ON PRIOR TO LIFT-OFF

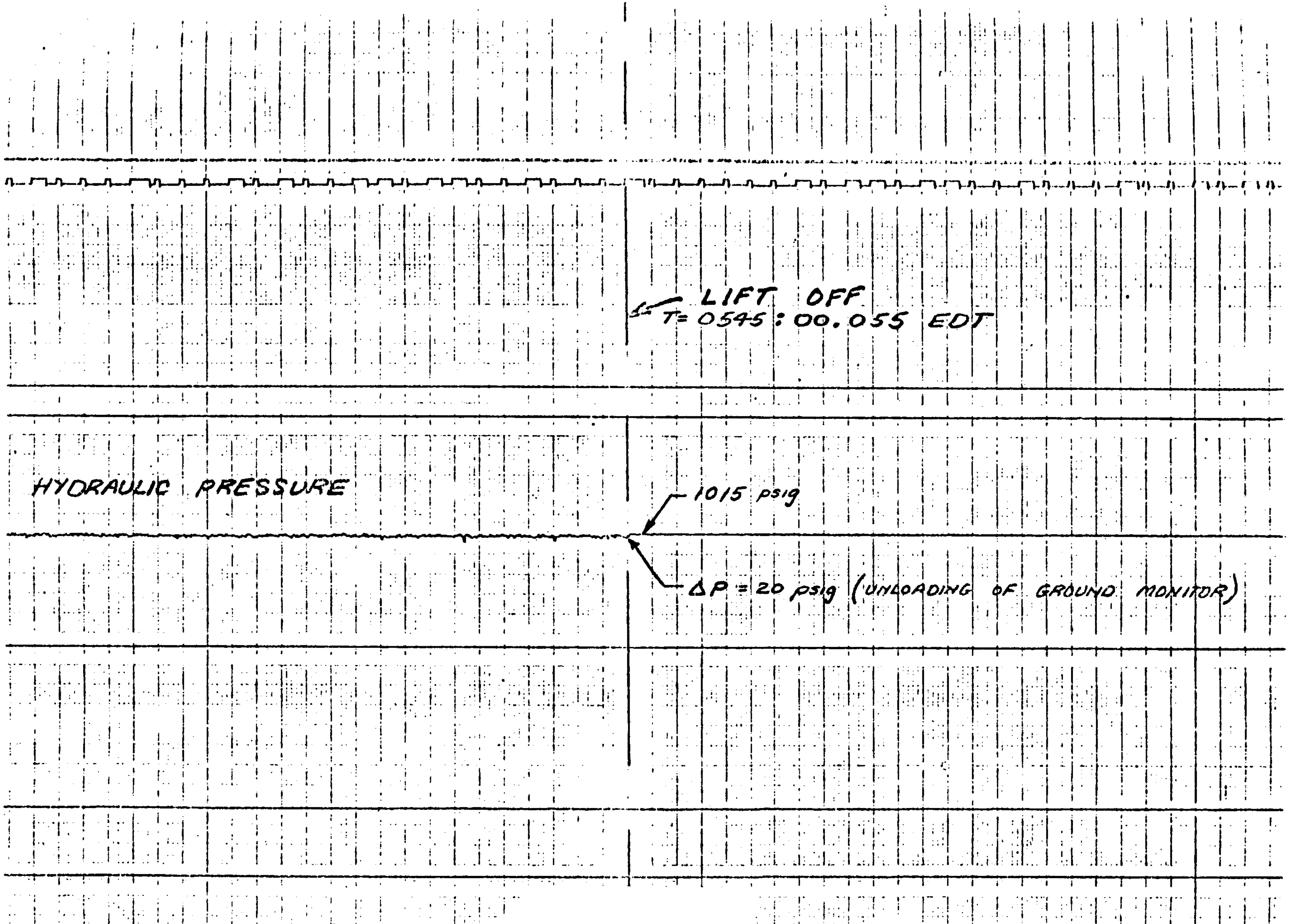


FIGURE 2-3, SYSTEM PRESSURE AT LIFT-OFF

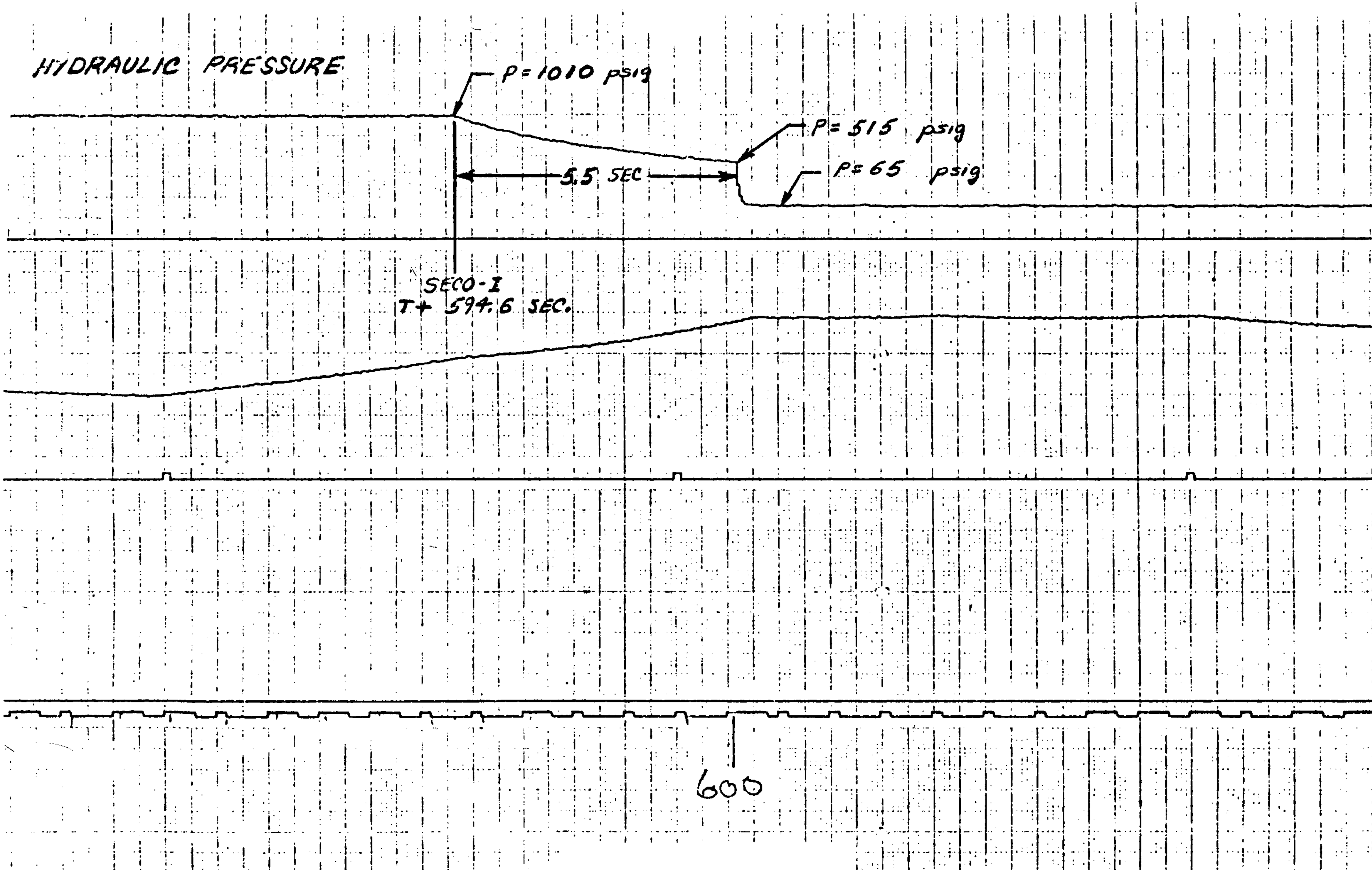


FIGURE 2-4, SECO-I SYSTEM BLEED DOWN

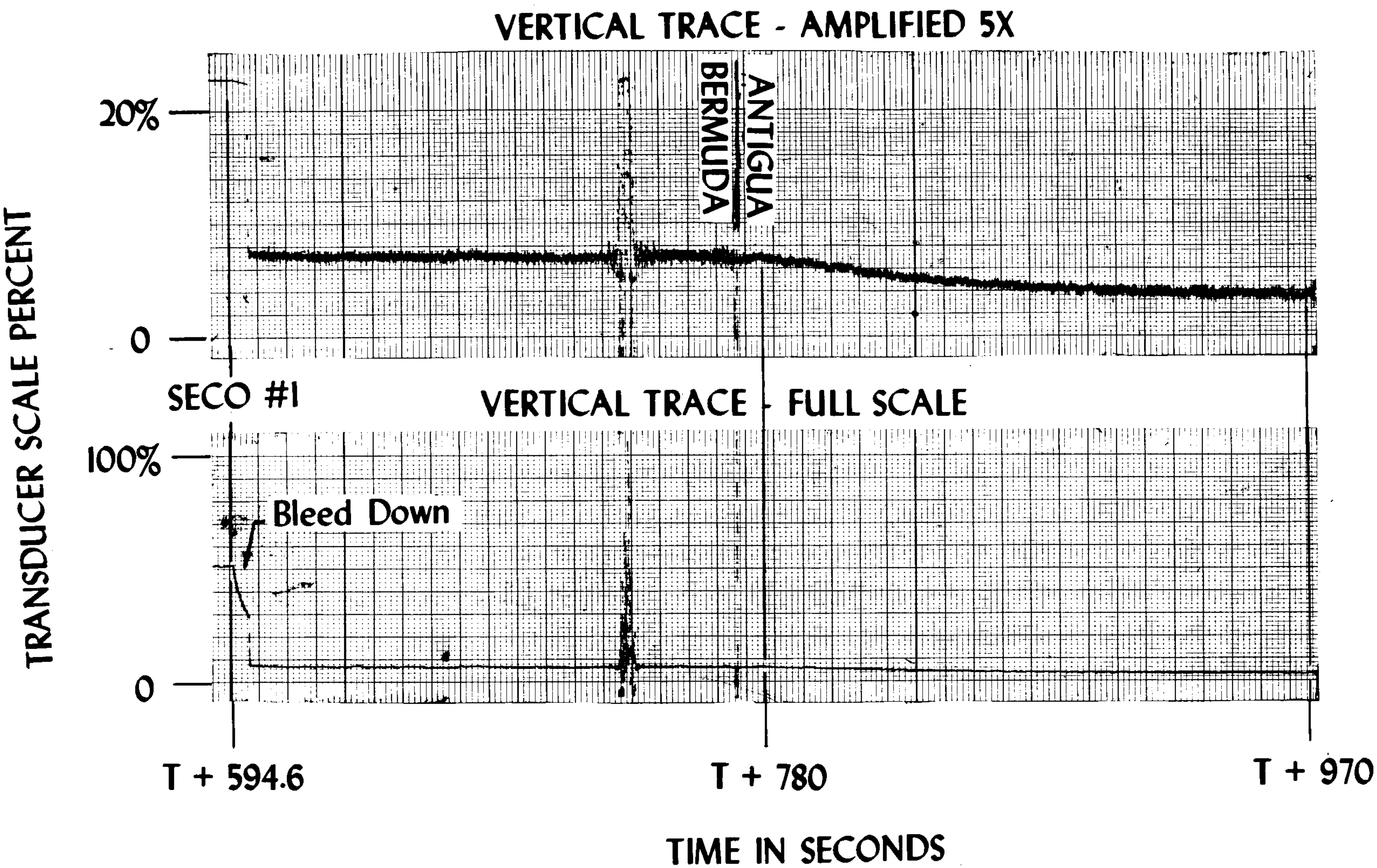


FIGURE 2-5, TELEMETRY TRACE - DELTA 85, HYDRAULIC, SHOWING INITIATION OF PRESSURE DECAY AT T+780

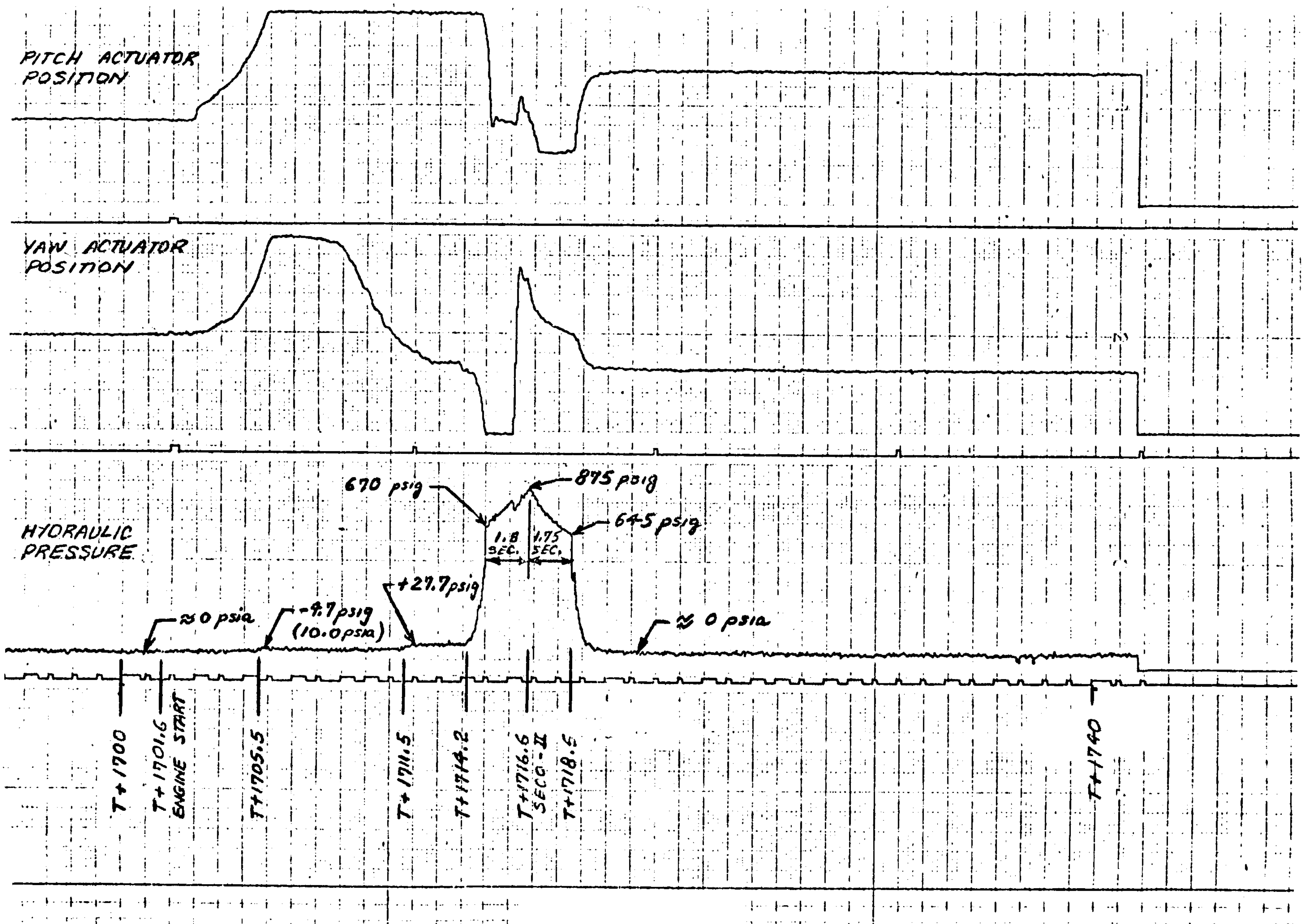


FIGURE 2-6, SECOND BURN

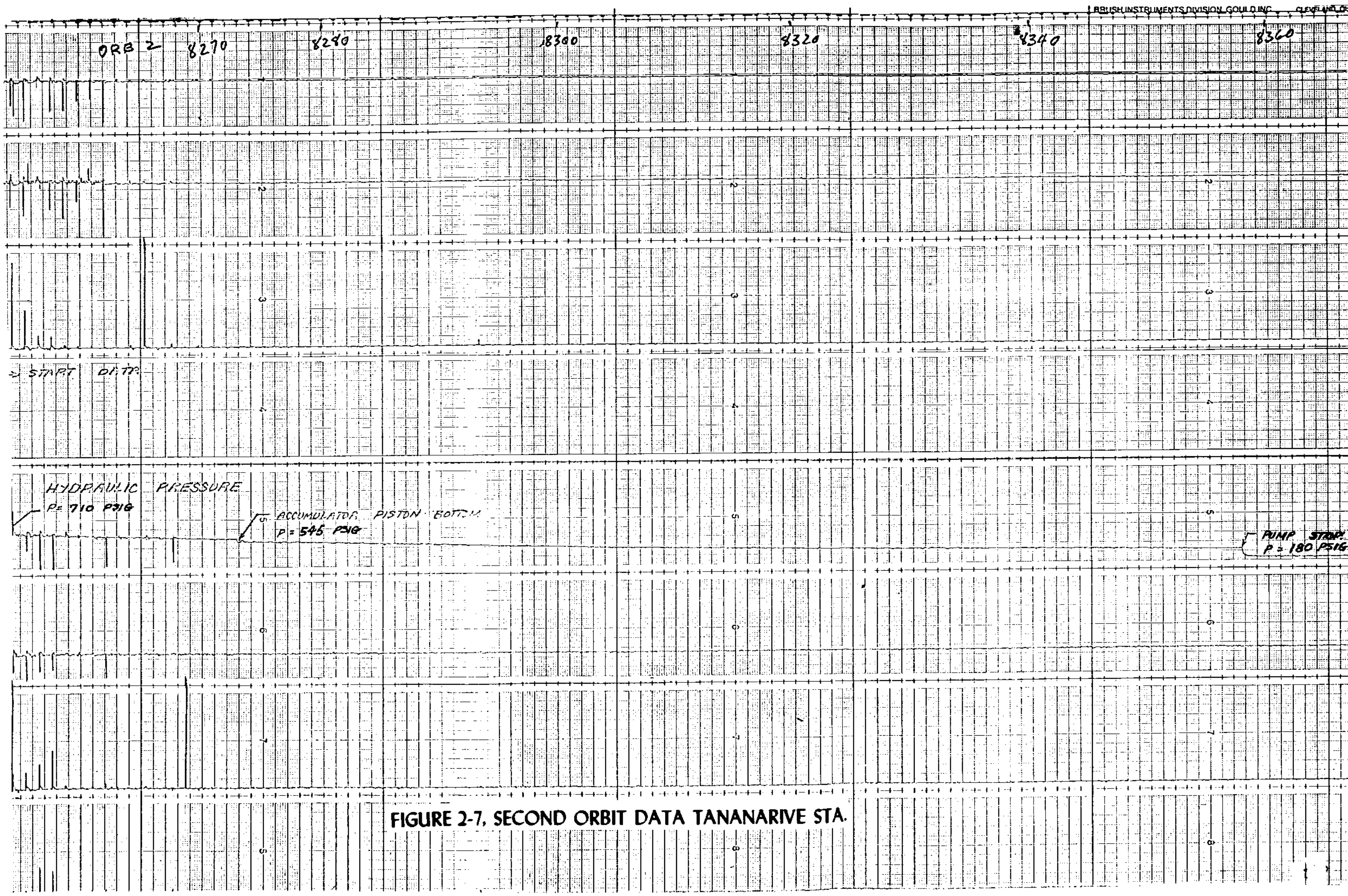


FIGURE 2-7, SECOND ORBIT DATA TANANARIVE STA.

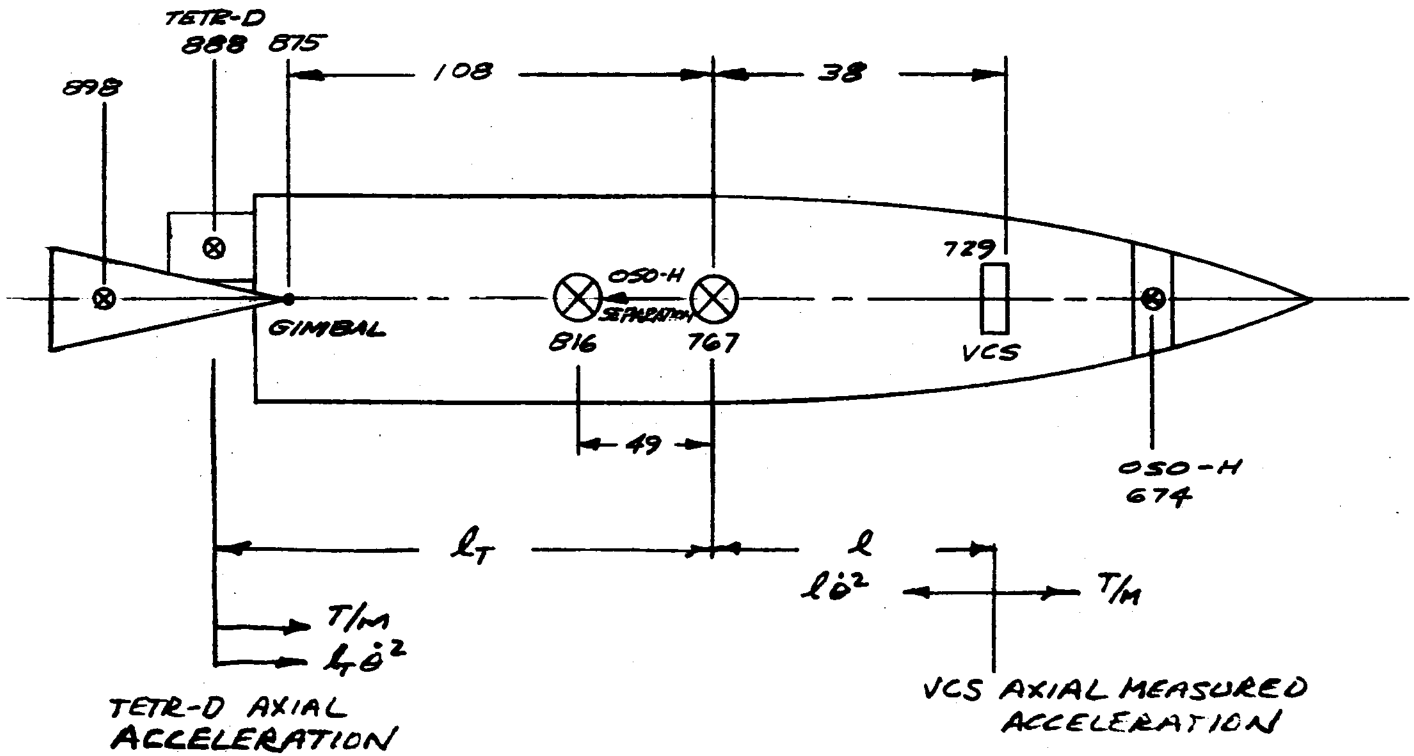
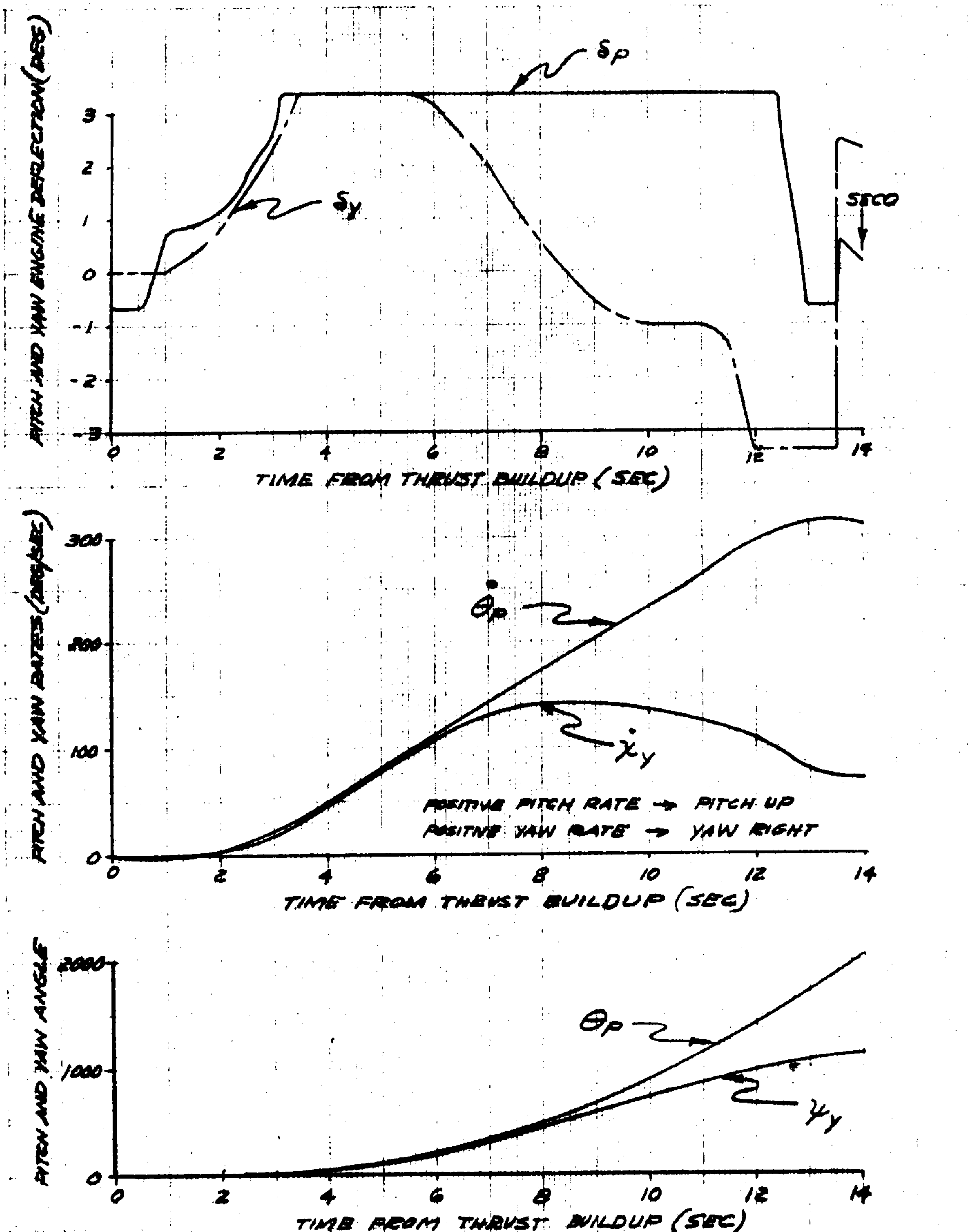


FIGURE 2-8, OSO-H SECOND STAGE VEHICLE DEFINITION



PITCH AND YAW ENGINE DEFLECTION (DEG)
δ_p
δ_y
SECO
TIME FROM THRUST BUILDUP (SEC)
PITCH AND YAW RATES (DEG/SEC)
$\dot{\theta}_p$
$\dot{\chi}_y$
POSITIVE PITCH RATE → PITCH UP
POSITIVE YAW RATE → YAW RIGHT
TIME FROM THRUST BUILDUP (SEC)
PITCH AND YAW ANGLE
θ_p
ψ_y
TIME FROM THRUST BUILDUP (SEC)

FIGURE 2-9

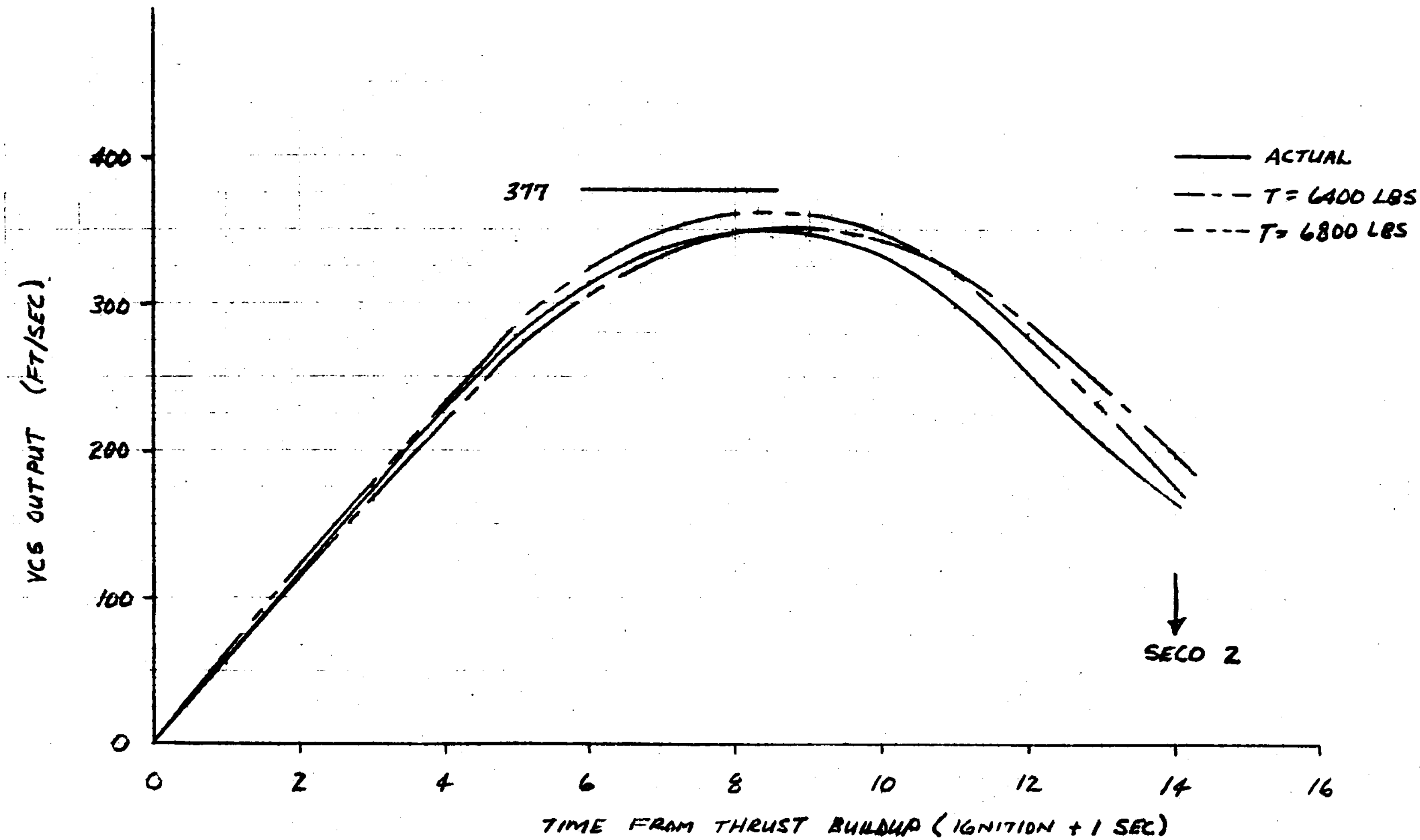
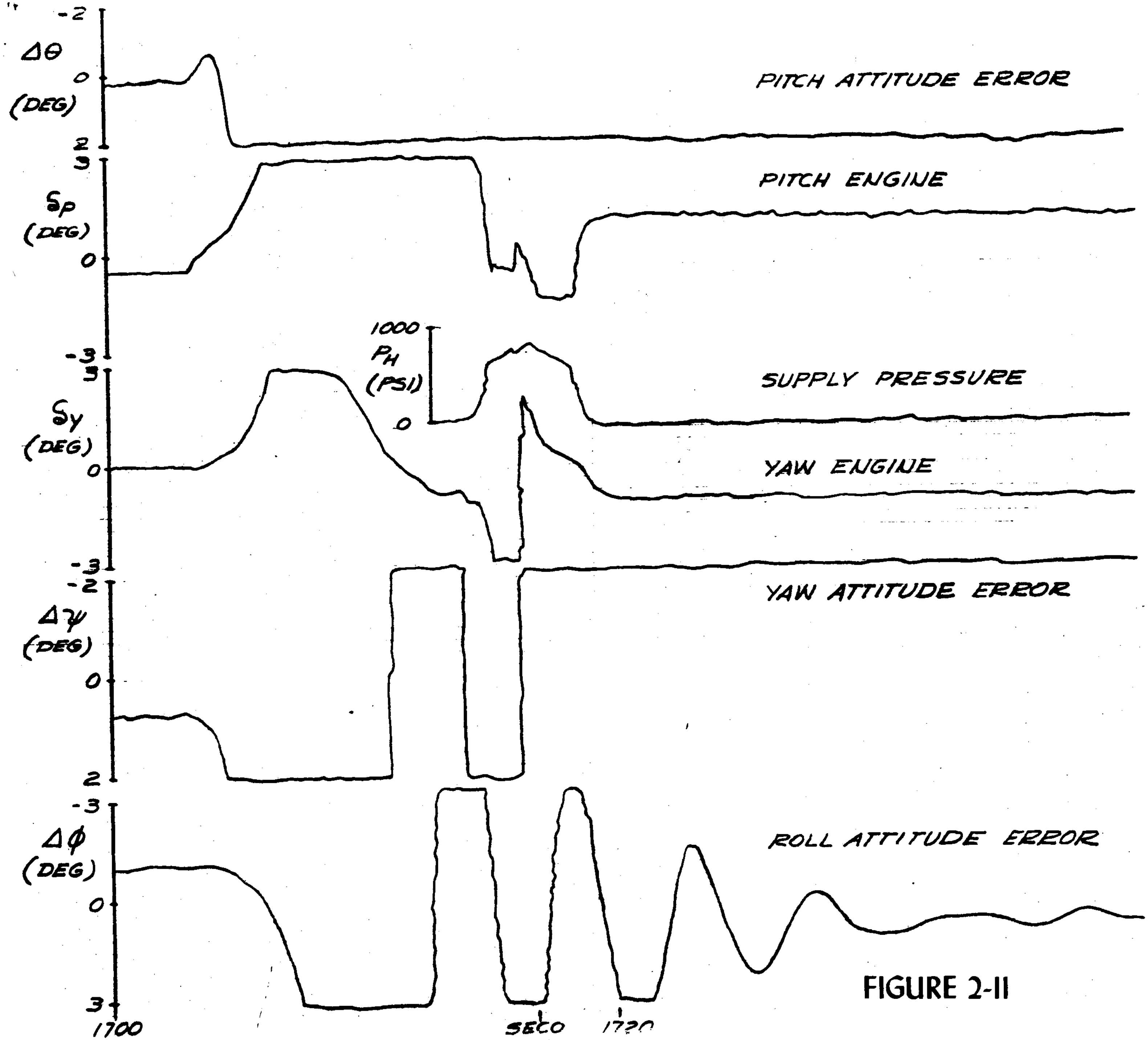


FIGURE 2-10, VCS OUTPUT RECONSTRUCTION



PITCH ATTITUDE ERROR
PITCH ENGINE
SUPPLY PRESSURE
YAW ENGINE
YAW ATTITUDE ERROR
ROLL ATTITUDE ERROR
$\Delta\theta$ (DEG)
δ_P (DEG)
δ_Y (DEG)
$\Delta\psi$ (DEG)
$\Delta\phi$ (DEG)
1000
P_H (PSI)
SECO
1700
1720

FIGURE 2-11

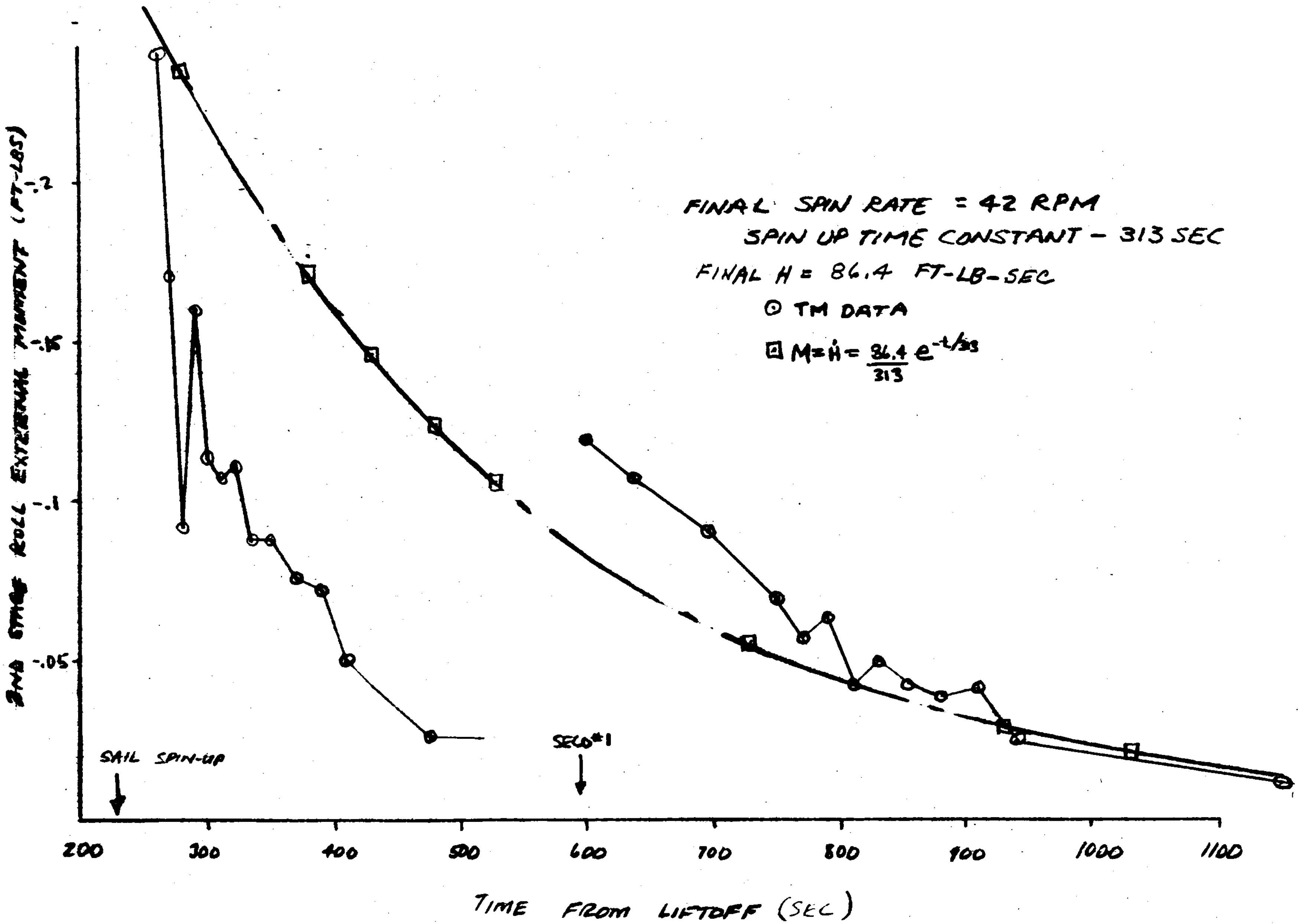


FIGURE 2-12,OSO-H 2nd STAGE EXTERNAL ROLL MOMENT

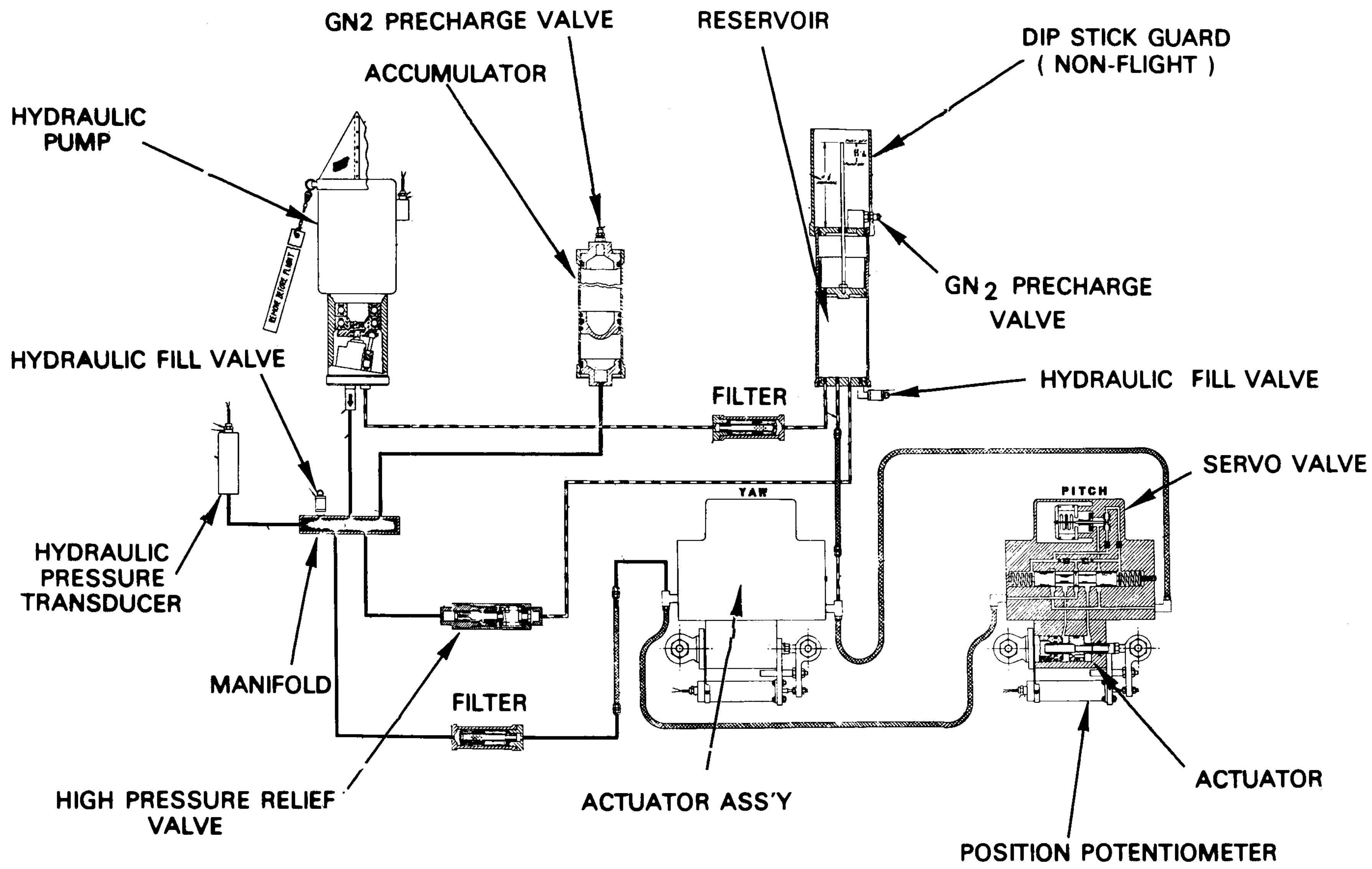


FIGURE 3-1, DIAGRAM-DELTA 85, STAGE II HYDRAULIC SYSTEM

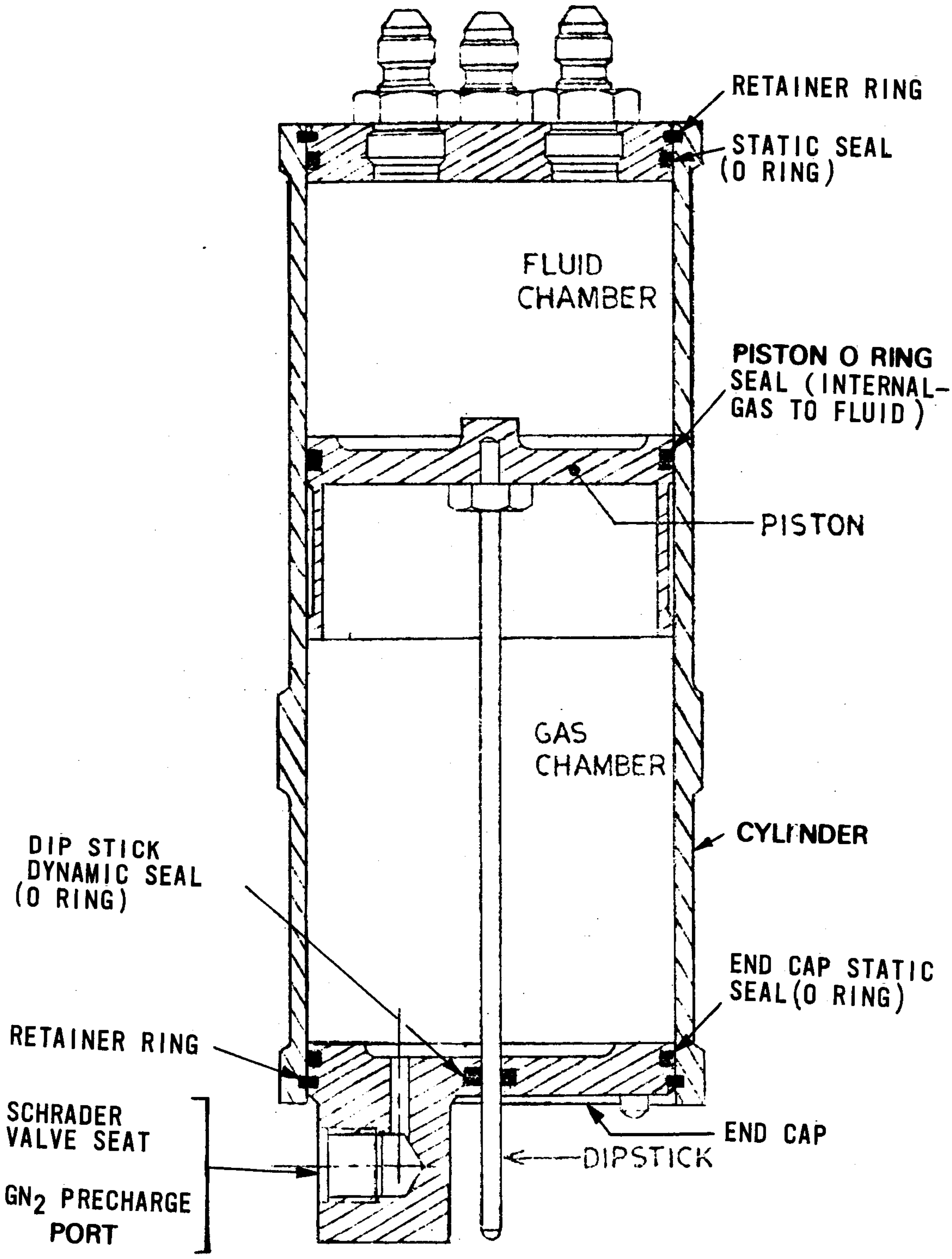


FIGURE 3-2, HYDRAULIC RESERVOIR

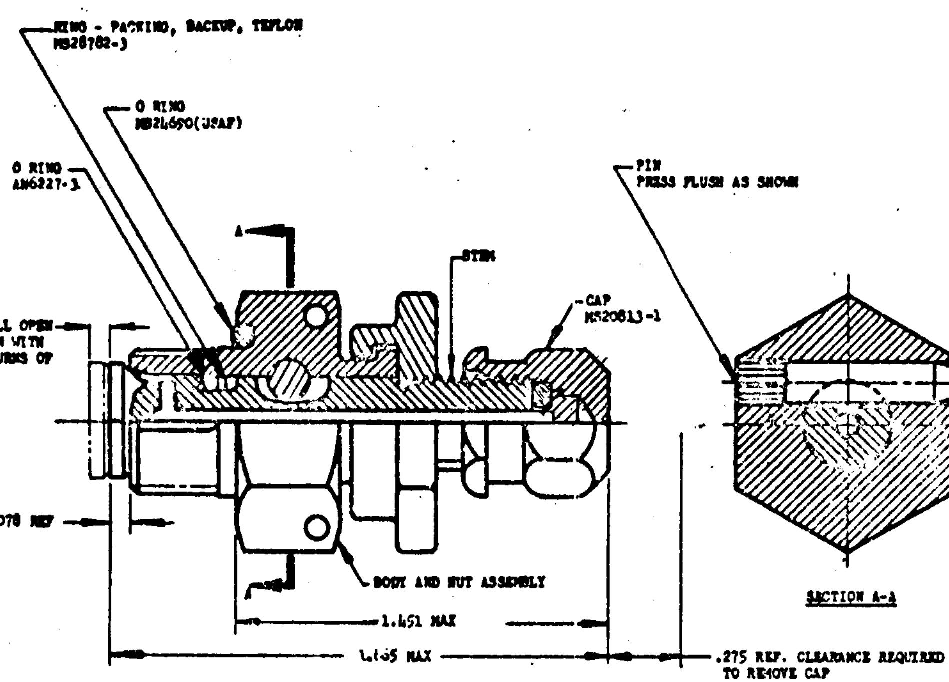


FIGURE 3-3, SCHRADER VALVE-GN_2 PRECHARGE

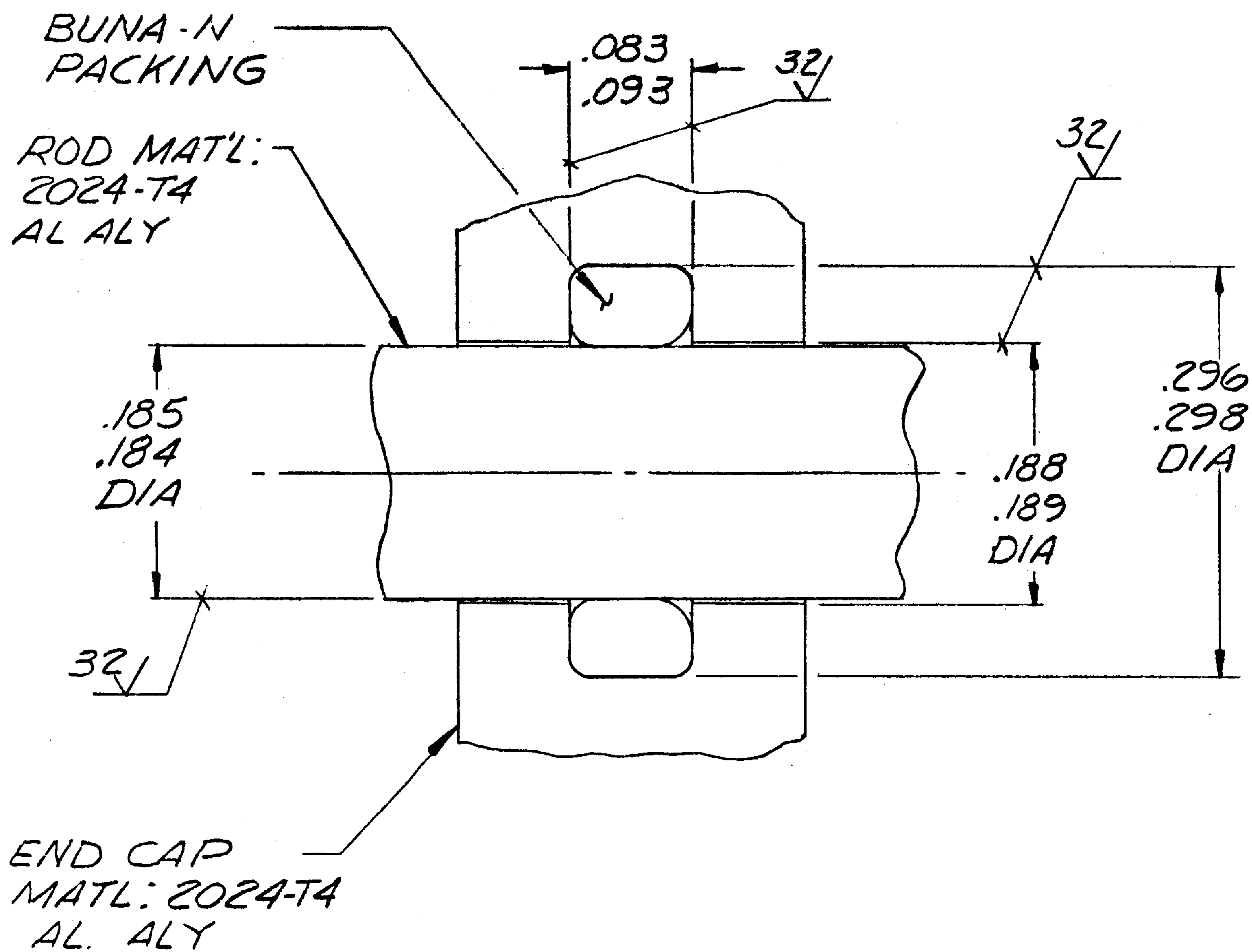


FIGURE 3-4, DIP STICK DYNAMIC SEAL

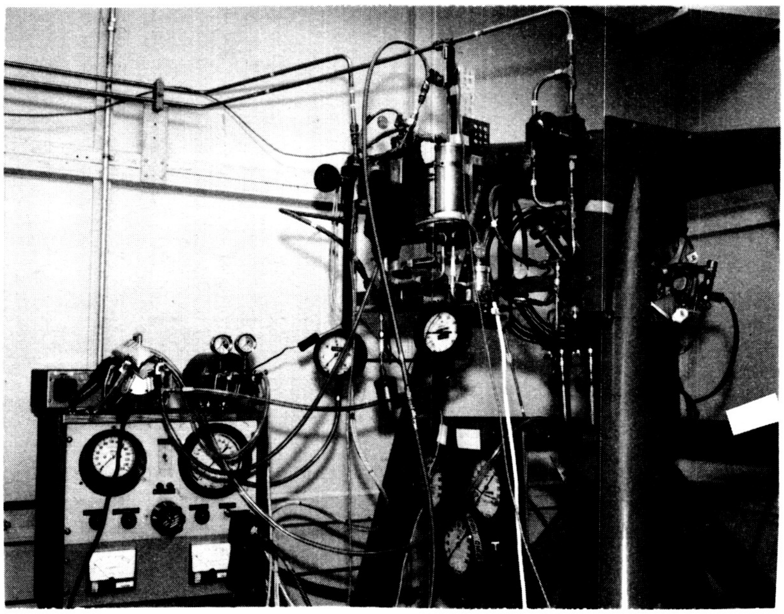


FIGURE 3-5, DELTA STAGE II HYDRAULIC SYSTEM TEST CONFIGURATION-VEHICLE SIMULATION-AT ALRC

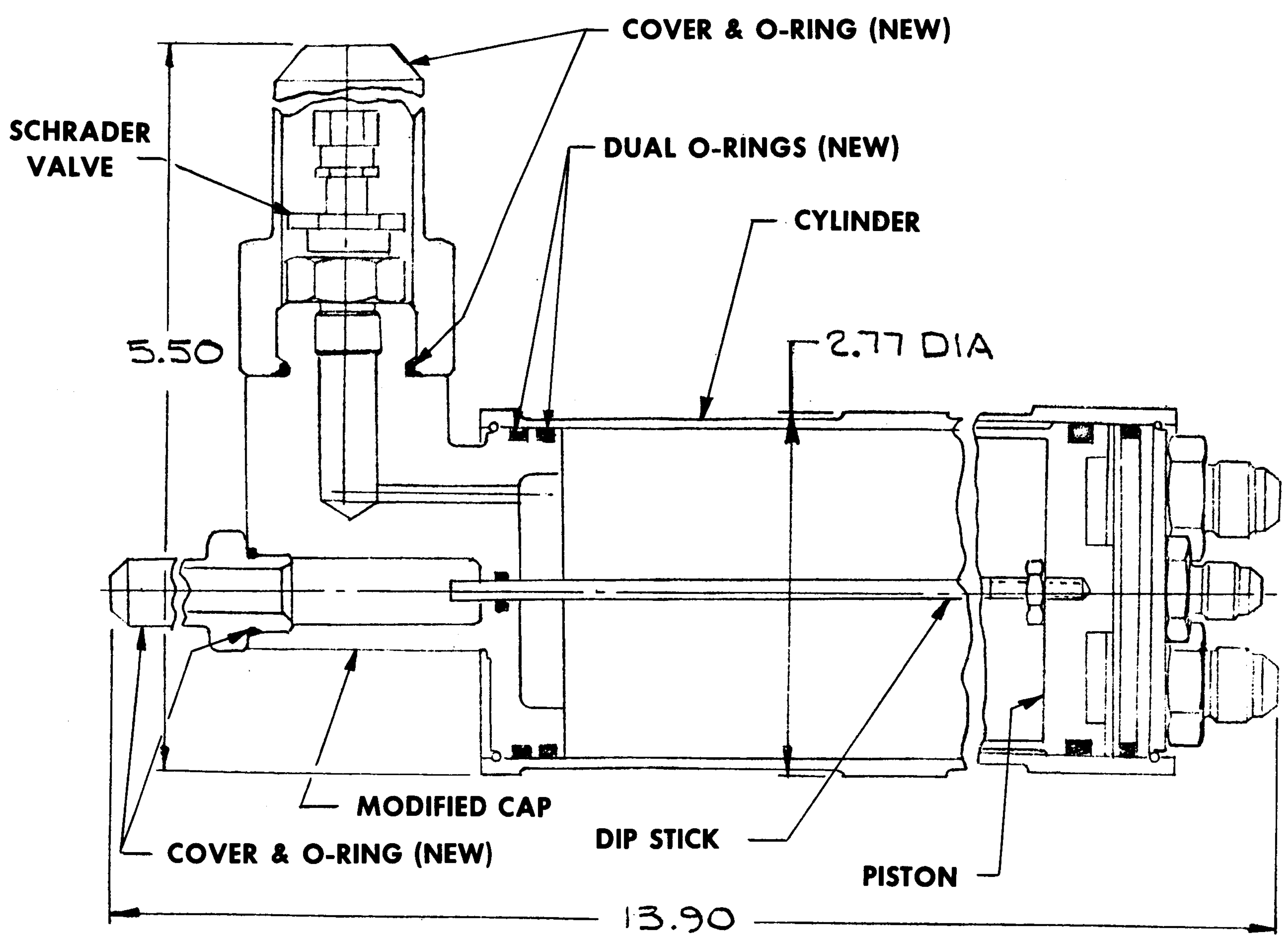


FIGURE 5-1, DELTA - 86 RESERVOIR ASS'Y

APPENDIX A

INVESTIGATIVE AUTHORITY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: SV

OCT 1971

TO: Goddard Space Flight Center
Attn: Dr. John F. Clark, Director

FROM: S/Associate Administrator for
Space Science and Applications

SUBJECT: OSO-H Launch Vehicle Anomaly Investigation

This is to confirm the conference phone call held by Dr. Naugle, Dr. Clark, Mr. Johnson, and Mr. Mahon to formulate plans for the subject investigation.

You are requested to initiate an investigation to determine the cause of the launch vehicle anomaly which occurred during the OSO-H launch and report your findings with the recommendations and corrective actions resulting therefrom.

In view of the impending ITOS-B and subsequent Delta launches, I request that this investigation and report be completed by the Goddard Space Flight Center as soon as possible.

John E. Naugle

John E. Naugle

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Alton E. Jones　　　　**DATE:** September 29, 1971

FROM : Office of the Director

SUBJECT: Delta 85 Anomaly Review Committee

You are requested to chair an Anomaly Review Committee to investigate the anomaly of the Delta 85 vehicle. You should select members from Goddard and other Centers you deem appropriate, with observers from NASA Headquarters and NOAA.

You are requested to submit a recommended membership by the close of business on October 1, 1971, and to submit an interim report on the reason for the anomaly by the close of business on October 14, 1971. This report must contain a preliminary assessment of the problem as well as any information pertinent to the next ITOS launch. The final report should be submitted by the close of business November 1, 1971 and must include a statement as to the cause of the Delta 85 anomaly and call out any recommended changes that may be considered necessary to avoid recurrence.

for John F. Clark

cc: Dr. Vaccaro
Mr. LaGow
Mr. Bourdeau
Mr. Mazur

APPENDIX B

DELTA 85 ANOMALY REVIEW COMMITTEE MEMBERSHIP

UNITED STATES GOVERNMENT

Memorandum

TO : Dr. John F. Clark
Director

DATE: October 1, 1971

FROM : Alton E. Jones
Chairman, Delta 85 Anomaly Review Committee

SUBJECT: Delta 85 Anomaly Review Committee

In response to your memorandum of September 29, 1971 the following personnel are nominated to serve as members of the Delta 85 Anomaly Review Committee:

Henry W. Price, Jr.	Goddard Space Flight Center
David H. Suddeth	Goddard Space Flight Center
Robert R. Drummond	Goddard Space Flight Center
Benjamin Seidenberg	Goddard Space Flight Center
Jack Evans	Goddard Space Flight Center
William A. Russell, Jr.	Goddard Space Flight Center
Frank W. Mokry	Kennedy Space Center
Victor Neiland	Marshall Space Flight Center

In addition to the regular committee members, the following will serve as observers:

Edward G. Albert	National Oceanic and Atmospheric Administration
Isaac Gillam IV	NASA Headquarters
William W. Jones	Goddard Space Flight Center
John M. Thole	Goddard Space Flight Center
Edward A. Rothenberg	Goddard Space Flight Center

Consultants will be called in as necessary.

Alton E. Jones
Alton E. Jones

cc: Dr. Vaccaro
Mr. LaGow
Mr. Bourdeau
Mr. Mazur

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

FILE 5173
OCT 4 1971

Mr. Miles Ross
Deputy Director
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

Mike

Dear ~~Mr. Ross~~:

This will confirm arrangements made by telephone for a Kennedy Space Center member on Goddard's Delta 85 Anomaly Review Committee.

It is our understanding that Mr. Frank W. Mokry from KSC will serve on the Committee which is chaired by Mr. Alton E. Jones of Goddard. We expect that both Centers will benefit from Mr. Mokry's participation.

Thank you for your cooperation.

Sincerely,

Donald P. Hearth
Deputy Director

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

FILE 5171

OCT 4 1971

Dr. William R. Lucas
Deputy Director - Technical
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Dear ~~Dr. Lucas~~ B.ll:

This will confirm arrangements made by telephone for a Marshall Space Flight Center member on Goddard's Delta 85 Anomaly Review Committee.

It is our understanding that Mr. Victor R. Neiland from your Center will serve on the Committee which is chaired by Mr. Alton E. Jones of Goddard. We expect that both Centers will benefit from Mr. Neiland's participation.

Thank you for your cooperation.

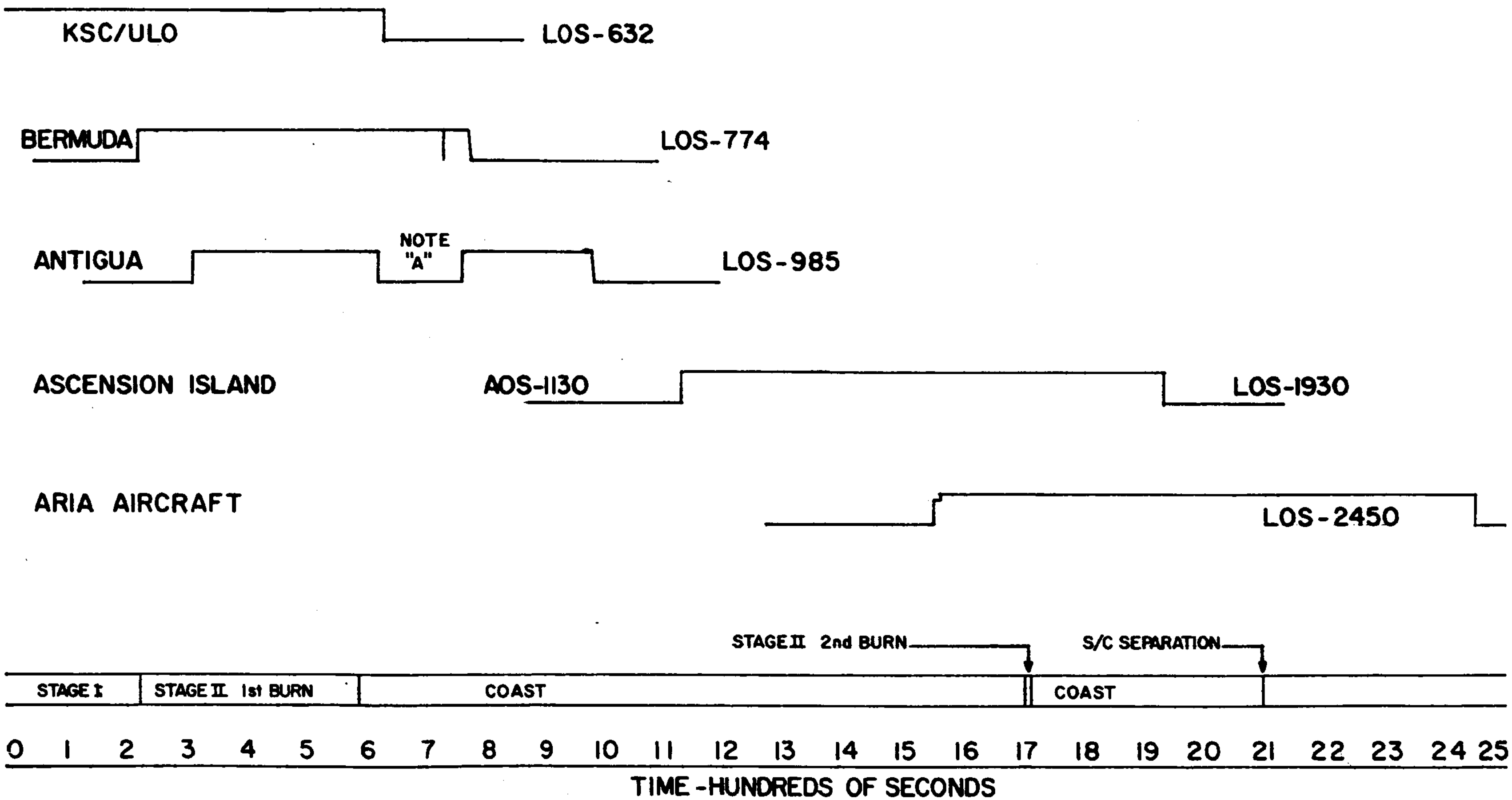
Sincerely,

Donald P. Hearth
Deputy Director

APPENDIX C

DELTA 85 TELEMETRY COVERAGE

DELTA 85 ACTUAL TELEMETRY COVERAGE
LAUNCH PHASE



NOTE "A"- ANTIGUA DATA LOST FOR 136 SECONDS DUE TO CIRCUIT BREAKER FAILURE

DELTA 85 - TELEMETRY

SECOND STAGE ORBITAL COVERAGE

	AOS	LOS
TANANARIVE	T + 2220	T + 2871
CARNARVON	T + 3156	T + 3760
GUAM	T + 4017	T + 4575
HAWAII	T + 4789	T + 5393
ULO-WTR	T + 5371	T + 5687
ULO-ETR	T + 6053	T + 6582
TANANARIVE	T + 8251	T + 8889

APPENDIX D

DELTA 85 SEQUENCE OF FLIGHT EVENTS

DELTA 85 SEQUENCE OF FLIGHT EVENTS

EVENT	ACTUAL	PROGRAMMED
Start Stage I Programmer Uncage Stage I Gyros Start Solid Motor Separation Timer	T + 0	T + 0
Begin Stage I Roll Program (Plus 1.00000 Deg/Sec Total Angle Plus 7.00000 Deg)	T + 2.0	T + 2
End Stage I Roll Program	T + 9.0	T + 9
Begin Stage I Pitch Program (Minus 0.46311 Deg/Sec Total Angle Minus 11.73382 Deg)	T + 9.3	T + 9.333
End First Pitch Rate	T + 34.6	T + 34.67
Begin Second Pitch Rate (Minus 0.44917 Deg/Sec Total Angle Minus 13.32687 Deg)	T + 35.0	T + 35
End Second Pitch Rate	T + 64.7	T + 64.67
Begin Third Pitch Rate (Minus 0.64605 Deg/Sec Total Angle Minus 24.98275 Deg) Enable Solid Motor Separation Circuitry	T + 65.0	T + 65
Solid Motor Separation Command Roll Gain Change Accumulator Purge On	T + 75.0	T + 75
Roll Gain Change (Backup) Uncage Stage II Roll Gyro Solid Motor Separation Backup Accumulator Purge On (Backup)	T + 79.8	T + 80
End Third Pitch Rate	T + 103.6	T + 103.67
Begin Fourth Pitch Rate (Minus 0.20446 Deg/Sec Total Angle Minus 19.62816 Deg)	T + 103.9	T + 104
Initiate Guidance Steering	T + 126.7	T + 124
Main Engine - Pitch and Yaw Rate and Attitude Gain Change Enable Pitch and Yaw Vernier Engines	T + 139.6	T + 140

EVENTS	ACTUAL	PROGRAMMED
Enable Stage II Ignition and Pyrotechnic Power	T + 203.2	T + 197
Enable MECO End Stage I Pitch Program	T + 199.4	T + 200
Stop BTL/WECO Commands	T + 214.5	T + 214.513
MECO	T + 219.6	T + 218.513
Start Stage II Programmer Blow Blast Band Bolts	T + 219.6	T + 218.513
Blow Stage I/II Separation Bolts Uncage Pitch and Yaw Gyros Enable Stage II Roll Control Start Stage II Engine Transfer Guidance Reference Power Roll Gyro Uncage (Backup)	T + 223.67$^{\Delta}$	T + 222.5
Begin Stage II Pitch Program (Minus 0.12167 Deg/Sec Total Angle Minus 44.66384 Deg)	T + 230.6	T + 229.5
Fairing Separation Enable Stage II Restart	T + 231.6	T + 230.5
Initiate VCS Channel I (ΔV Set for 4768 Ft/Sec)	T + 489.5	-----
Initiate VCS Channel #1 (Backup)	-----	T + 490.5
Arm Ox Probe and TPS Disable Ox Probe Failsafe	T + 538.6	T + 537.5
Stage II Engine Cutoff Command #1 End Stage II Pitch Program Turn Off Hydraulics Switch to Coast Phase Control Enable CDR Turn-Off Reset VCS Accumulator	T + 594.68$^{\Delta}$	T + 596.6
End Stage II Pitch Program (Backup)	-----	T + 618.5
Begin Coast Phase Pitch Program (Minus 0.47710 Deg/Sec Total Angle Minus 95.89710 Deg)	*	T + 635.5

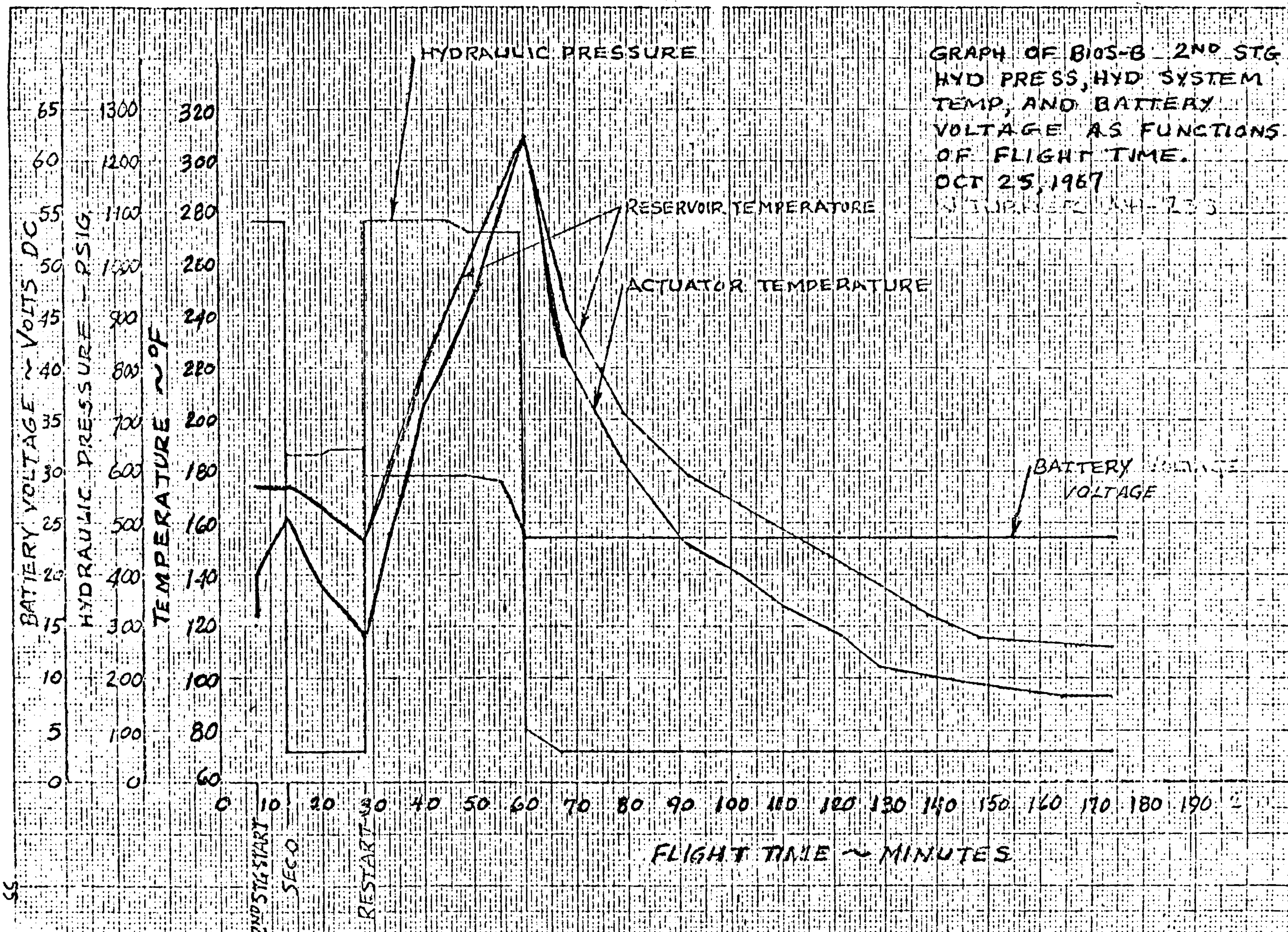
EVENT	ACTUAL	PROGRAMMED
Turn Off CDR's Turn Off BTL/WECO	T + 661.6	T + 660.5
End Coast Phase Pitch Program	T + 837.6	T + 836.5
Restart Conditioning Turn On Hydraulics Initiate Ullage Jets Disarm Ox Probe and TPS Initiate VCS Channel #2 (ΔV Set for 377 Ft/Sec) Disable VCS Channel #1	T + 1654.62$^{\Delta}$	T + 1653.5
Restart Stage II Engine Switch to Powered Phase Control	T + 1701.63$^{\Delta}$	T + 1700.5
Rearm Ox Probe and TPS Turn Off Ullage Jets	T + 1706.64$^{\Delta}$	T + 1705.5
Stage II Engine Cutoff Command #2 Turn Off Hydraulics Switch to Coast Phase Control	T + 1716.74$^{\Delta}$	T + 1707.3
Begin Coast Phase Yaw Program (Minus 0.62883 Deg/Sec Total Angle Minus 18.23607 Deg)	T + 1724.6	T + 1723.5
End Coast Phase Yaw Program	T + 1753.6	T + 1752.5
Payload Separation Blow PLD/Stage II Separation Bolts Fire Retros Start TETR-D Separation TDR's	T + 1996.6	T + 1995.5
TETR-D Separation	*	T + 3095.5

* Flight data not available.

NOTE: The above data is hand reduced except for times noted thus (Δ) which were obtained from digital tab run.

APPENDIX E

BIOS-B HYDRAULIC SYSTEM DATA


GRAPH OF BIOS-B 2ND STG
HYD PRESS, HYD SYSTEM
TEMP, AND BATTERY
VOLTAGE AS FUNCTIONS
OF FLIGHT TIME.
OCT 25, 1967
HYDRAULIC PRESSURE
RESERVOIR TEMPERATURE
ACTUATOR TEMPERATURE
BATTERY VOLTAGE
BATTERY VOLTAGE ~ VOLTS DC
HYDRAULIC PRESSURE – PSIG
TEMPERATURE ~ °F
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
320
300
280
260
240
220
200
180
160
140
120
100
80
60
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
2ND STG START
SECO
RESTART
FLIGHT TIME ~ MINUTES

APPENDIX F

SECOND BURN CONTROL SYSTEM ANALYSIS

UNITED STATES GOVERNMENT

Memorandum

732:334:JHD:pap

TO : Henry C. Hoffman, Head
Stabilization and Control Branch

DATE: 18 November 1971

FROM : James H. Donohue

SUBJECT: Delta 85 Second Burn Control System Anomaly Analysis

Delta 85 experienced a hydraulic system failure prior to second burn so that pressure to the pitch and yaw engine actuators was not present until about 11.6 seconds into the 14 second burn. During the period of pressure absence the actuators could not follow the gyro attitude error commands causing the booster and payload to spin up to as high as 67 rpm. When the hydraulic pressure came up, the actuators tried to follow the error signals. However, the available hydraulic torque was not sufficient to overcome the inertial and engine thrust misalignment torques about the engine pivot producing peculiar actuator motion (Figure 1). Shortly after SECO hydraulic pressure reduced and the actuators settled at their dynamic equilibrium positions which were +1.4 degrees in pitch and -1.1 degree in yaw. The purpose of this report is to present a plausible quantitative evaluation of the actuator performance.

The first step in defining the inertial torques about the engine pivot is the determination of the spin rate time history. This was accomplished using the Velocity Control System acceleromater telemetry data and evaluating:

$$\omega = \left(\frac{\frac{F}{M(t)} - a_s(t)}{r_A(t)} \right)^{1/2}$$

<u>where</u>

ω = spin rate
F = engine thrust
$M(t)$ = system mass
$r_A(t)$ = distance from system center of mass to accelerometer
$a_s(t)$ = sensed acceleration

The Resulting Spin Rate time history is shown in Figure 2, where the 67 rpm peak rate occurs shortly after the pitch actuator comes off its stop. The change in the rate after SECO corresponds quite closely to the theoretical change expected from either the pitch or yaw jet torques (40 ft-lb) both of which are activated at SECO. The spin rate at payload separation was approximately 55 rpm.

As seen from Figure 1, shortly after ignition both actuators hit their +3.4 degree stops. This motion is attributed to thrust misalignment with respect to the engine pivot point. These torques were calculated to be 208 ft-lb in pitch and 56 ft-lb in yaw. The pitch thrust misalignment torque was calculated using the fact that the pitch attitude error rate is zero .84 seconds after ignition and the model:

$$\ddot{\theta}\text{(Pitch Booster Acceleration)} = \frac{F(R+L)\delta(t)}{I_{s/c}} - \frac{T_M}{I_{s/c}}$$

where

F - engine thrust
$(R+L)$ - distance from system cm to engine cm
T_M - misalignment torque
$I_{s/c}$ - booster pitch MOI

Setting the time integration to zero and evaluating at t = .84 seconds permits determination of the misalignment torque.

These misalignment torques cause slow actuator motion because the actuator is almost in a fluid lock condition. The centering springs (Figure 3) position the spool such that oil is trapped in the main cylinder. The misalignment load on the cylinder piston causes it to move in one direction as fluid flows through the 13/1000 inch "orificed" channel through the main piston. Simplified calculations based on ideal orifice geometry show that a 5/1000 inch orifice diameter would account for the initial actuator motion.

The yaw thrust misalignment torque about the pivot was determined by equating it to the centrifugal torque at about 5 seconds after ignition where the actuator appears to be at equilibrium. The spin rate at this time was 25 rpm.

$$T_M = M_G(R+L)\, L\omega^2(\delta_R - \delta)$$

where M_G - engine mass (4.93 slugs)
L - distance from system center of mass to engine CM(23.15")
δ_R - Dynamic equilibrium actuator position (Engine-off)-1.1 Deg.
δ - actual actuator position (+3.4 deg)

For the most part the spin up torque is attributed to the pitch actuator being on its stop for about nine seconds. The MOI of the booster about the pitch axis is about 5 slug-ft^2 larger than the yaw axis MOI. The product of inertia with respect to the control axis has not been available and therefore the exact location of the maximum principle axis relative to the pitch axis is now know. It is felt to be quite close to the pitch axis. In evaluating the dynamic torques about the engine pivot the spin rate was assumed to be about the pitch axis.

The torque about the pivot point is modeled as:

$$T_{GP} = T_H + T_{\dot{\theta}^2} + T_{\ddot{\theta}^2} + T_{MP}$$

$$T_{GY} = T_H + T_{\dot{\theta}^2} + T_{MY}$$

where

T_M (Hydraulic Control Torque) = PAr

P = Hydraulic Pressure
A = Piston Area (.9 in^2)
r = Moment Arm from Actuator to Engine Pivot (6 in)

$T_{\dot{\theta}^2}$ (Torque Due to centrifugal load on engine cm) $= M_G(R+L)L\dot{\theta}^2(\delta_R-\delta)$

$T_{\ddot{\theta}}$ (Torque due to tangential load on engine cm) $= \dfrac{M_G(R+L)LFR}{I_{s/c}}\delta$

T_M - Engine thrust misalignment torque

Table 1 shows these torques for various points on Figure 1 where the actuators are stopped. $T_{\dot{\theta}^2}$ was computed using 65 rpm. Also, the actuator position required for equilibrium was computed and a comparison of columns (1) and (2) shows the degree to which the gimbal torque model actually fits the observed actuator motion.

TABLE 1

PT	(1) δ (Deg)	δ_R (Deg)	$T_{\dot{\theta}^2}$ (ft-lb)	T_M (ft-lb)	$T_{\ddot{\theta}}$ (ft-lb)	T_H (ft-lb)	T_G (ft-lb)	(2) Computed Equilibrium δ (Deg)
1P	+3.4	+1.4	-183	+208	+79	-80	+24	+stop
2P	-.3	↓	+156	+208	-7	-353	+4	-.3
3P	-.5	↓	+174	+208	-12	-390	-20	-.8
5P	-.1	↓	+137	+208	-2	-400	-57	-.9
6P	-1.5	↓	+266	-	-	-380	-114	-2.7
7P	-1.5	↓	+266	-	-	-300	-34	-1.8
2Y 3Y	-3.4	-1.1	+211	+56	-	-353	-86	-stop
3Y	-3.4	↓	+211	+56	-	-390	-123	-stop
5Y	+2.0	↓	-284	+56	-	+400	+172	+3.3

Positive torque wants to change actuator position positively.

Sign of hydraulic torque opposite to attitude error polarity.

At point 1P the pitch actuator is being held on its stop because the engine thrust misalignment and acceleration torques exceed the centrifugal and hydraulic torques. Just after this point, the hydraulic pressure rises causing the pitch actuator to move toward its negative stop as dictated by the positive attitude error. As it passes the dynamic reference position (+1.4 deg) the centrifugal and engine misalignment torques oppose its motion and equilibrium is reached at point 2P. The calculated gimbal torque at this point substantiates this behavior quite well. Although the hydraulic pressure rises slightly between 2P and 3P the actuator remains fixed most likely due to gimbal stiction. Just after point 3P the yaw error signal, which causes the yaw gimbal to be on its negative stop, changes polarity. At this time the yaw misalignment and centrifugal torques assist the hydraulic torque and the actuator responds quite rapidly. The yaw flow demand causes the hydraulic system to starve and the accumulator supplies fluid to the system causing a change in pressure. This results in a reduced hydraulic torque and the pitch actuator moves toward its "engine off" equilibrium position (+1.4 deg).

This pressure transient is of short duration and the pitch actuator starts to drive again in the negative direction stopping at 5P. This position is 0.2 degrees different than the 2P actuator position. A probable cause of this type of performance is gimbal stiction and the rate at which the actuator is moving as it approaches the equilibrium point.

Stopping of the yaw actuator at 5Y is not verified as well from the torque equilibrium calculations. Based on these calculations the actuator should have settled at +3.4 degrees. A possible explanation for this behavior is that additional torque is present due to propulsive hosing restraints. Information on this phenomenon is presently being sought.

SECO occurs shortly after 5P. At this time the hydraulic system pump is shut down causing a pressure tail off as the accumulator discharges. Also, the gyro attitude error is switched from the powered flight shaping network to the jet-coast attitude control system shaping network. Normally, the actuator will null as in fact the yaw actuator did. However, the engine shaping network is not shorted to ground and if the capacitors in this network are charged they will supply an error signal to the actuator servo and it will respond as long as pressure exists. This was most certainly the situation in pitch where the shaping network capacitors were being charged by the saturated pitch error signal for about 12 seconds.

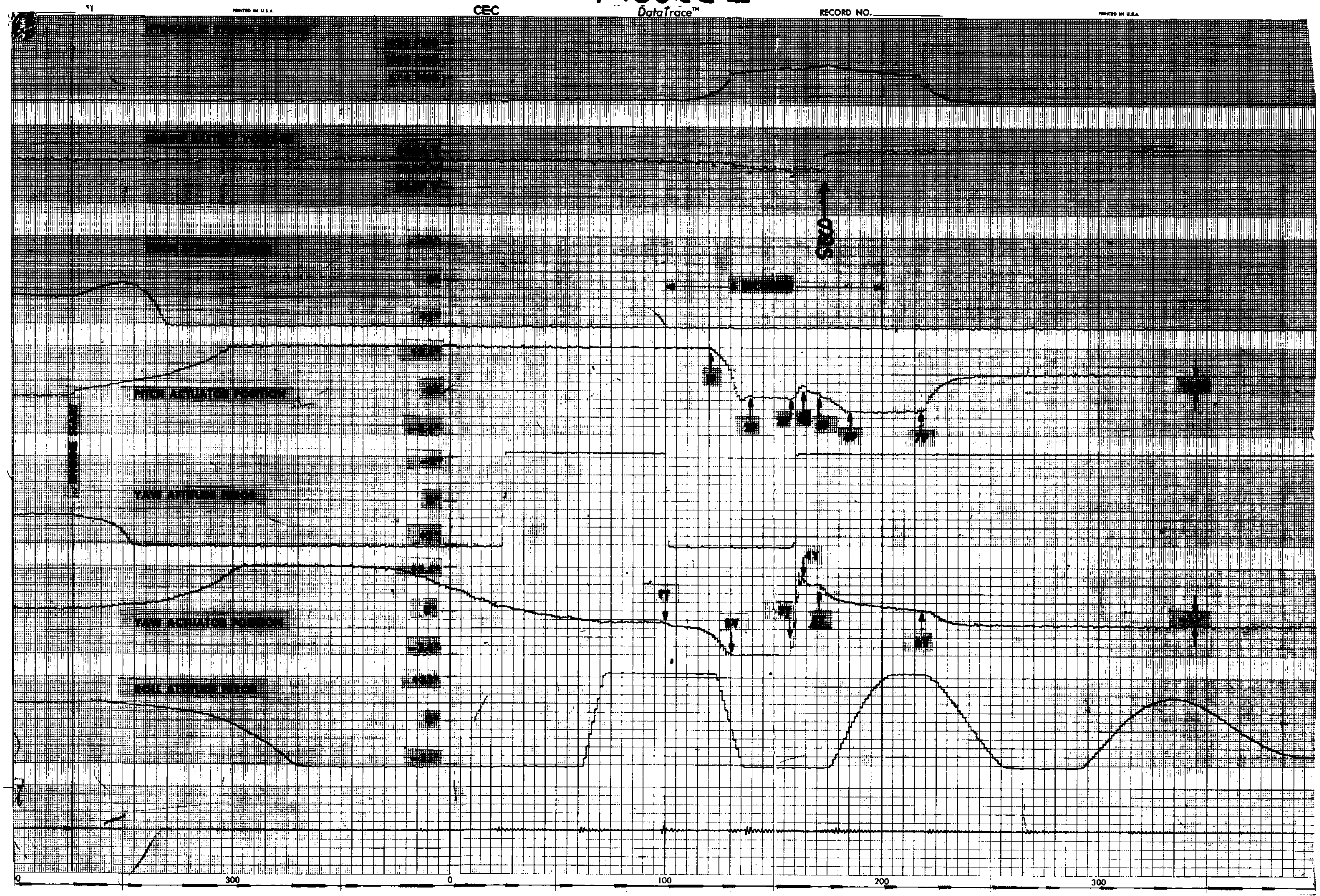
Therefore instead of driving to a zero position after 5P, the pitch actuator followed the shaping network error signal and moved toward its negative stop, coming to rest at -1.5 deg (6P). The gimbal torque calculations indicate that it should have gone somewhat further (-2.7 deg). Again, stiction torque is the most likely cause for this discrepancy. With the engine off the centrifugal force on the engine cm tries to pull it out of the mono-ball socket (2700 lbs of force) whereas during powered flight the engine is pushed into the socket.

After point 7P pressure drops rapidly and both actuators settle at their dynamic equilibrium point. These equilibrium points can be realized if the engine center of mass is offset from its roll axis, about 0.7 inches. Qualitative information received from Douglas indicates the propulsive hosing and fittings do offset the engine center of mass in the proper direction to account for the polarity of the equilibrium points. Verification of the magnitude of the cm offset requires further study.

James H. Donohue

James H. Donohue

FIGURE 1



CEC
DataTrace™
RECORD NO.
PRINTED IN U.S.A.
SRO
PITCH ACTUATOR POSITION
YAW ATTITUDE ERROR
YAW ACTUATOR POSITION
ROLL ATTITUDE ERROR
0
300
0
100
200
300

FIGURE 2

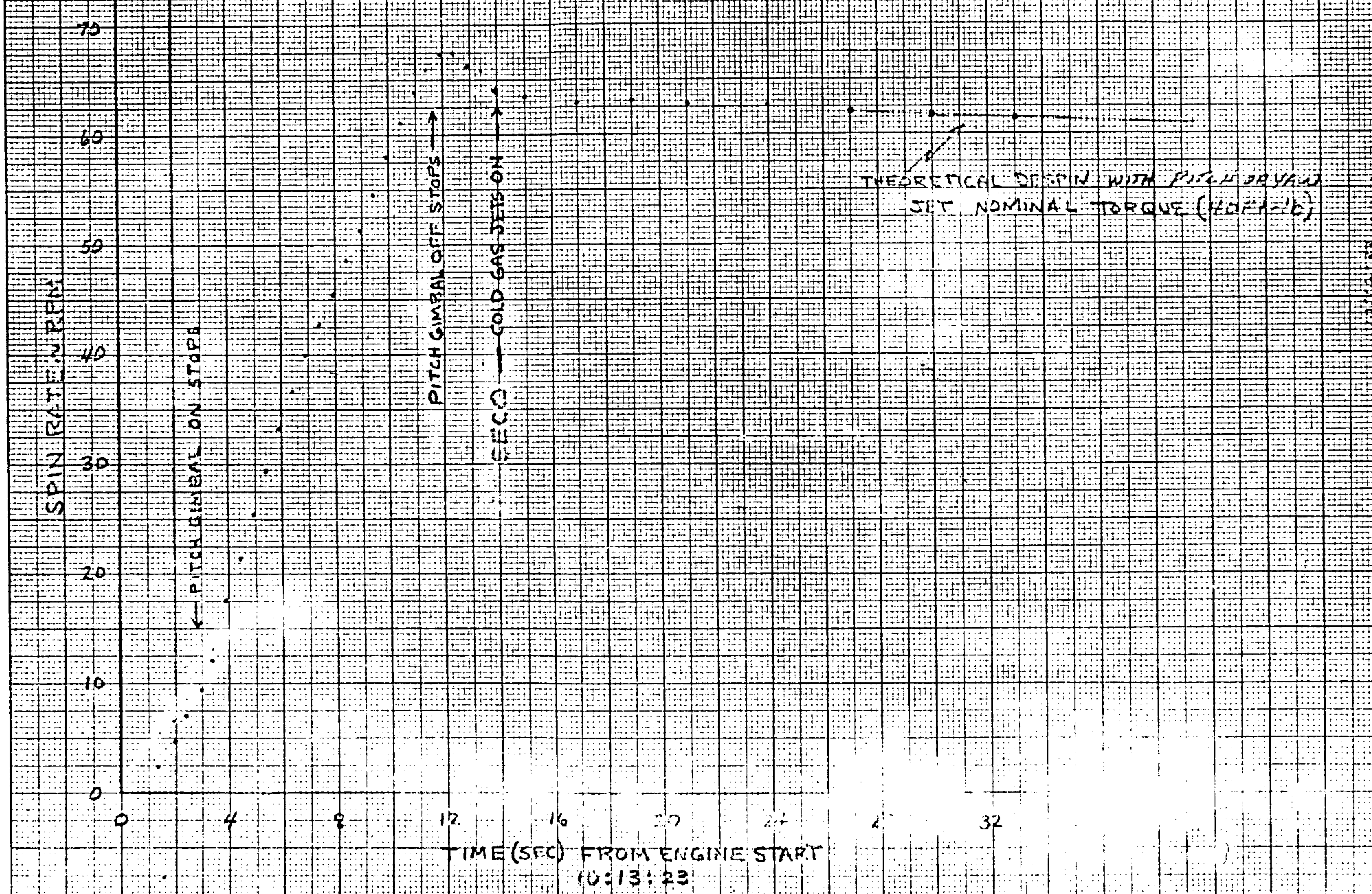

SPIN RATE ~ RPM
0
10
20
30
40
50
60
70
0
4
8
12
16
32
← PITCH GIMBAL ON STOPS
PITCH GIMBAL OFF STOPS →
SECO — COLD GAS JETS ON →
THEORETICAL DESPIN WITH PITCH OR YAW
JET NOMINAL TORQUE
TIME (SEC) FROM ENGINE START
10:13:23

FIGURE 3

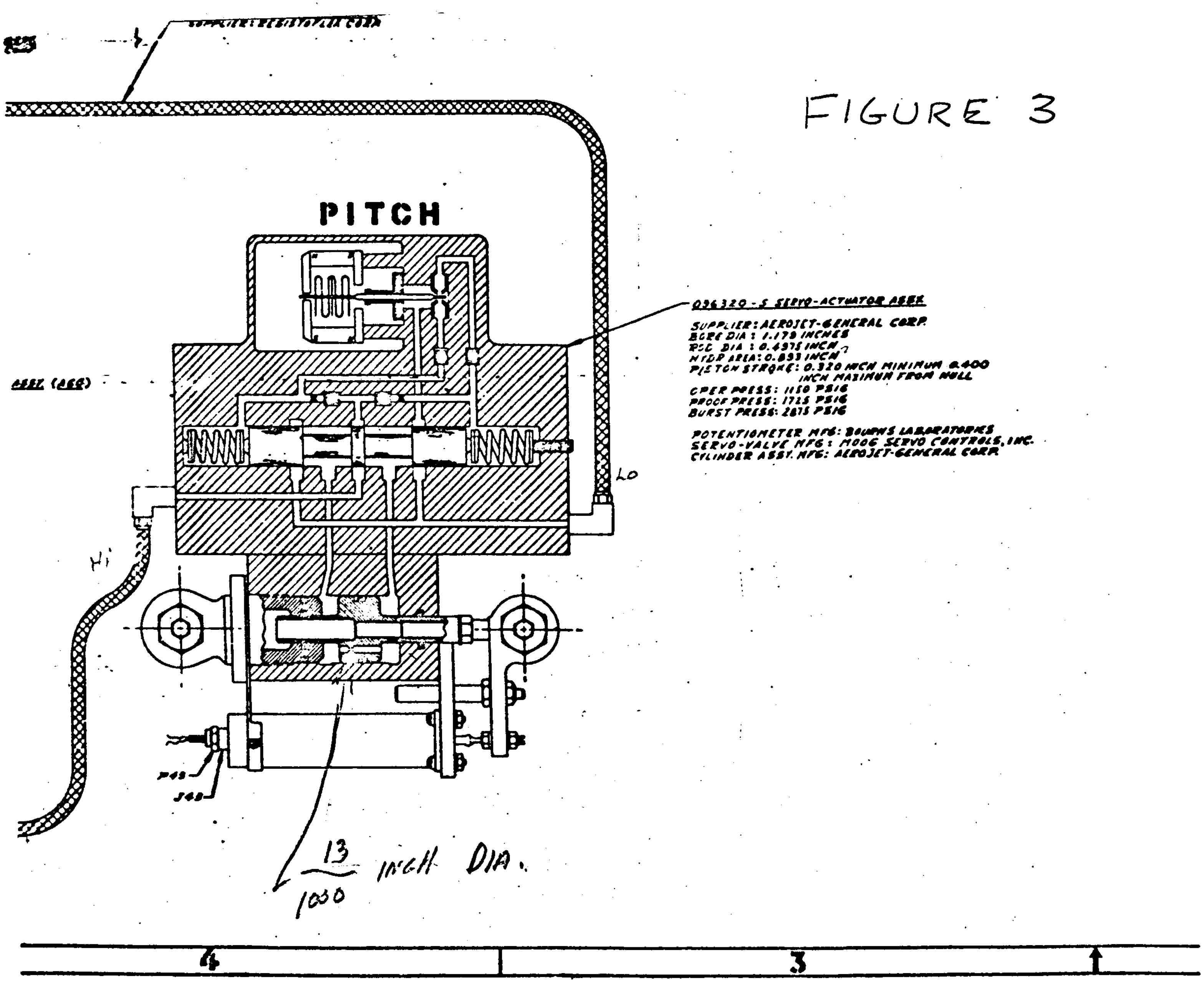
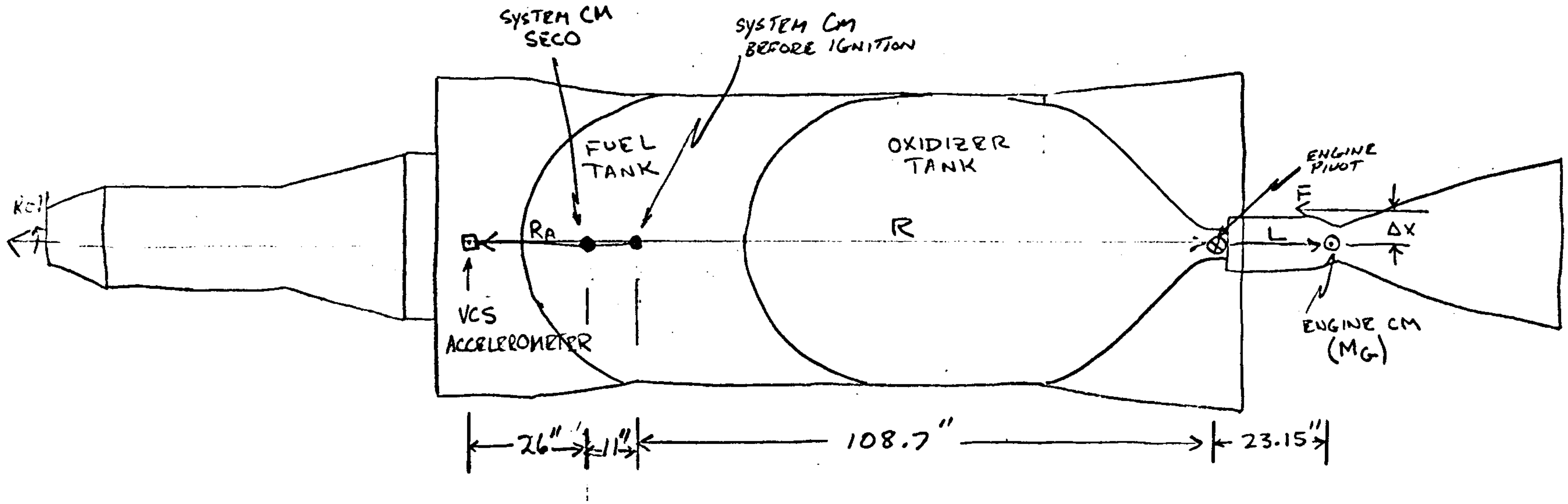

PITCH
SUPPLIER: RESISTOFLEX CORP.
096320 - 5 SERVO-ACTUATOR ASSY
SUPPLIER: AEROJET-GENERAL CORP.
BORE DIA: 1.179 INCHES
ROD DIA: 0.4375 INCH
HYDR AREA: 0.893 INCH
PISTON STROKE: 0.320 INCH MINIMUM 0.400 INCH MAXIMUM FROM NULL
OPER PRESS: 1150 PSIG
PROOF PRESS: 1725 PSIG
BURST PRESS: 2875 PSIG
POTENTIOMETER MFG: BOURNS LABORATORIES
SERVO-VALVE MFG: MOOG SERVO CONTROLS, INC.
CYLINDER ASSY. MFG: AEROJET-GENERAL CORP.
Hi
Lo
P43
J43
13/1000 INCH DIA.
4
3

FIGURE 4



ENGINE MASS (M_G)	— 4.93 slugs	
ENGINE MOI ABOUT PIVOT (I_G)	— 28.6 slug ft²	
SYSTEM PITCH MOI	— 5131.6 slug ft²	END OF BURN
SYSTEM YAW MOI	— 5125.9 " "	END OF BURN
SYSTEM PITCH MOI	— 5734.8 " "	IGNITION
SYSTEM YAW MOI	— 5729.1	IGNITION
SYSTEM WEIGHT	— 3287 lbs	END OF BURN
" "	— 3678 lbs	IGNITION
ENGINE THRUST (F)	— 6400 lbs	

OPTIONAL FORM NO. 10
MAY [illegible] EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Henry C. Hoffman, Head
Stabilization and Control Branch

732:336:JD:bb
DATE: 24 November 1971

FROM : James H. Donohue

SUBJECT: Additional Delta 85 Control System Analysis

Reference: Memo to H. Hoffman from J. Donohue, Titled "Delta 85 Second Burn Control System Anomaly Analysis (732:334)

In the referenced memorandum, the "Non-Centering" motion of the pitch actuator after SECO was qualitatively attributed to the fact that although the Gyro reference is switched from the shaping network at SECO, the network capacitors are charged during the previous 12 second period where the pitch attitude error is saturated. After SECO these capacitors discharged providing negative actuator electrical command. The actuator responded until the available hydraulic torque was cancelled by the inertial torque. After 2 seconds, the available hydraulic torque reduced abruptly due to hydraulic system pressure change (accumulator discharged) and the actuator returned to its dynamic equilibrium position (+1.4 deg). The purpose of this memorandum is to quantitatively substantiate the presence of the electrical actuator command for 2 seconds following SECO.

The Gyro gain is 10 volts/deg. and it can operate linearily up to ± 15 degrees from a mechanical standpoint. However, the demodulator amplifier saturates at 80 volts or 8 degrees. Prior to second stage ignition the Gyro is switched to the shaping network and a constant voltage (V_G) causes the following network voltage responses:

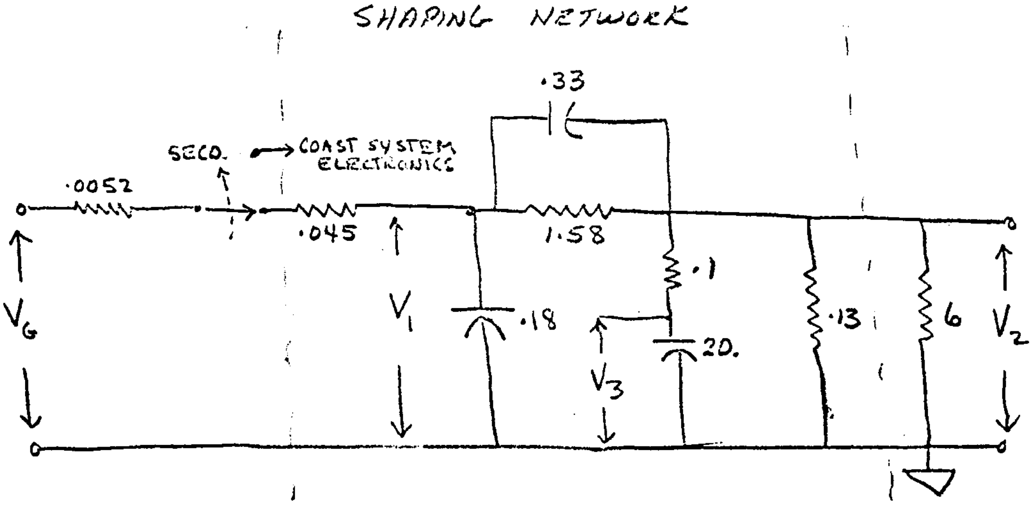
$$V_1\ (t) = V_G\ (-.568e^{-26.80t} -.402e^{-238.3t} -.000995e^{-.2258t})$$

$$V_2\ (t) = V_G\ (+.482e^{-26.80t} - .520e^{-238.3t} -.0362e^{-.2258t}+.0742)$$

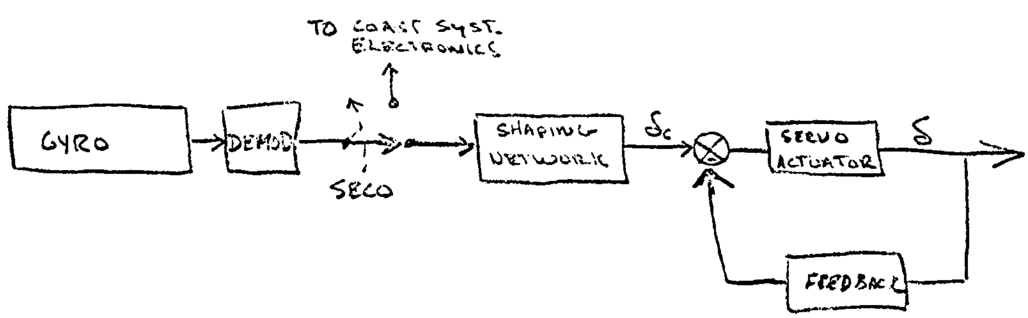
$$V_3\ (t) = V_G\ (-.00917e^{-26.80t} +.00109e^{-238.3t}-.0661e^{-.2258t}+.0742)$$

where V_2 is the actuator command voltage.

SHAPING NETWORK



ALL RESISTORS ~ MEG Ω
CAPACITORS ~ μ f



.561 $\frac{\text{volts}}{\text{DEG}}$ (DC GAIN)

After SECO the command voltage is:

$$
\begin{aligned}
V_2(t^1) = {} & e^{-.2167t^1}\,(.00362V_1(t_{SECO}) - .004V_2(t_{SECO}) + .5646V_3(t_{SECO})) \\
& + e^{-1.237t^1}\,(.0092V_1(t_{SECO}) - .0059V_2(t_{SECO}) - .0021V_3(t_{SECO})) \\
& + e^{-152.8t^1}\,(-.012V_1(t_{SECO}) + 1.006V_2(t_{SECO}) - .5625V_3(t_{SECO}))
\end{aligned}
$$

where $t^1 = t - t_{SECO}$

The actuator position command is related to the voltage command thru:

$$\delta_C \text{ (DEG)} = \frac{-V_2}{.561}$$

Evaluating the previous expressions where a +80 volt attitude error signal is present for 12 seconds prior to SECO gives the actuator electrical command response:

$$\delta(t^1) = -6.03e^{-.2167t^1} - 1.193e^{-1.237t^1} - 3.082e^{-152.8t^1}$$

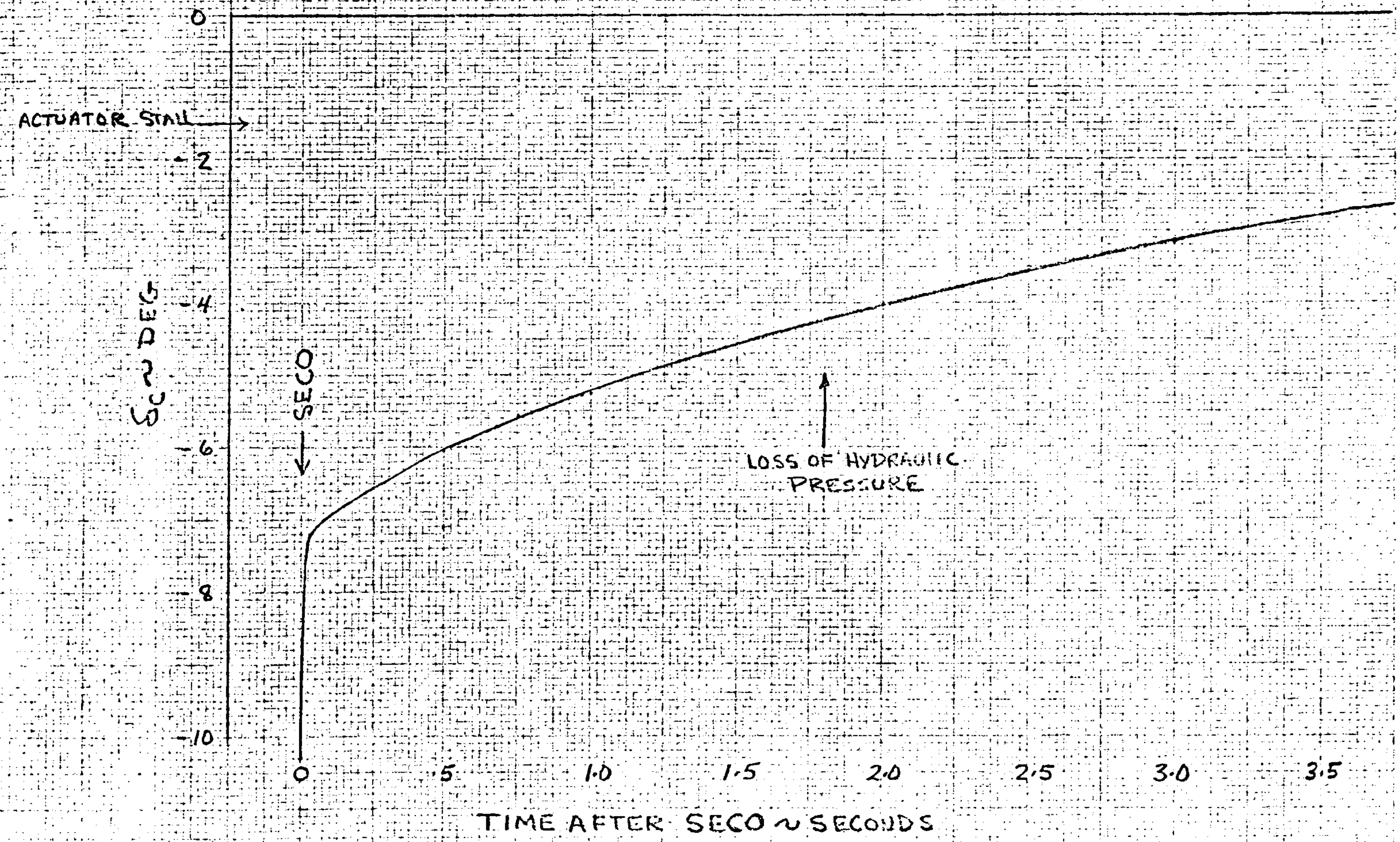
Figure 2 shows the command time history which is negative for the 2 second period after SECO. Moreover, this command is always more negative than the actual actuator position which stops at -1.5 degrees due to the cancellation of the available hydraulic torque by the inertial torque (Ref. 1). Clearly then, the "Non-Centering" pitch actuator motion after SECO is caused by the negative electrical command to the servo actuator.

James H. Donohue

James H. Donohue

FIGURE 1

PITCH ACTUATOR ELECTRICAL COMMAND AFTER SECO (DELTA 85)



APPENDIX G

DELTA 85 CONFIGURATION AND FIRST FLIGHT ITEMS

DELTA 85 - CONFIGURATION

ITEM	MODEL	S/N
FIRST STAGE	DSV-3L-1	20022
FIRST STAGE SOLIDS	TX-354-5	270 271 272
INTERSTAGE	DSV-3L-2	20024
SECOND STAGE	DSV-3E-4	20249
ATTACH FITTING	DSV-3E-6	20251
FAIRING	DSV-3E-7	20247

DELTA 85 FIRST FLIGHT ITEMS

FIRST STAGE

- Six solid lanyard configuration for three solid vehicle
- Pogo suppression system & instrumentation
- Main engine vibration instrumentation
- Hydraulic return line temp. monitor
- FABU & engine heater current monitor
- Stainless steel hydraulic QD shrouds (AGE)

SECOND STAGE

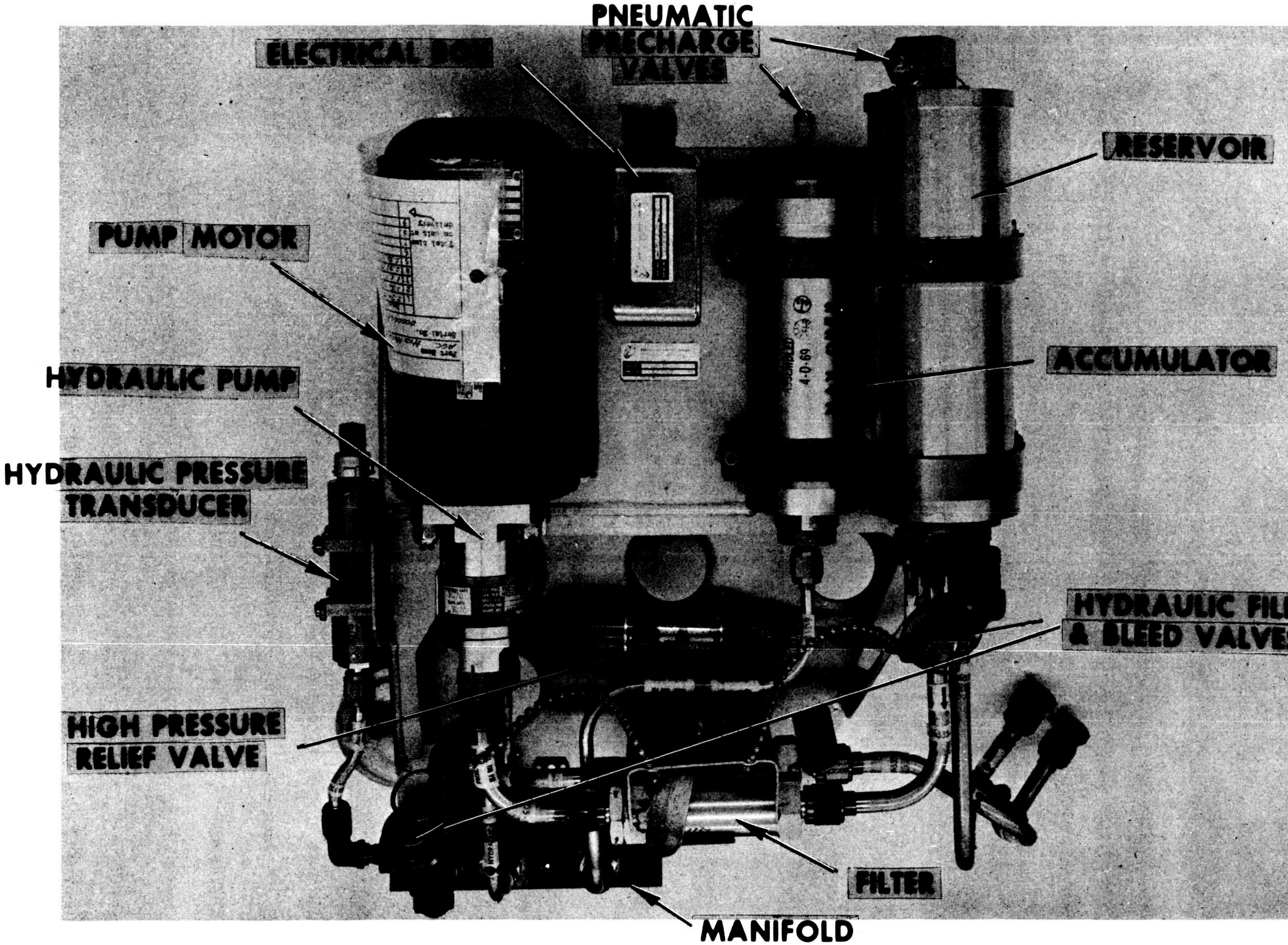
- Dimple Motor timers for TETR separation
- Pitch & yaw coast shaping network with expanded jet switching dead bands
- RF shield
- Spacecraft cleanliness handling
- Suppression diodes in ullage valve relay coil circuits

FAIRING

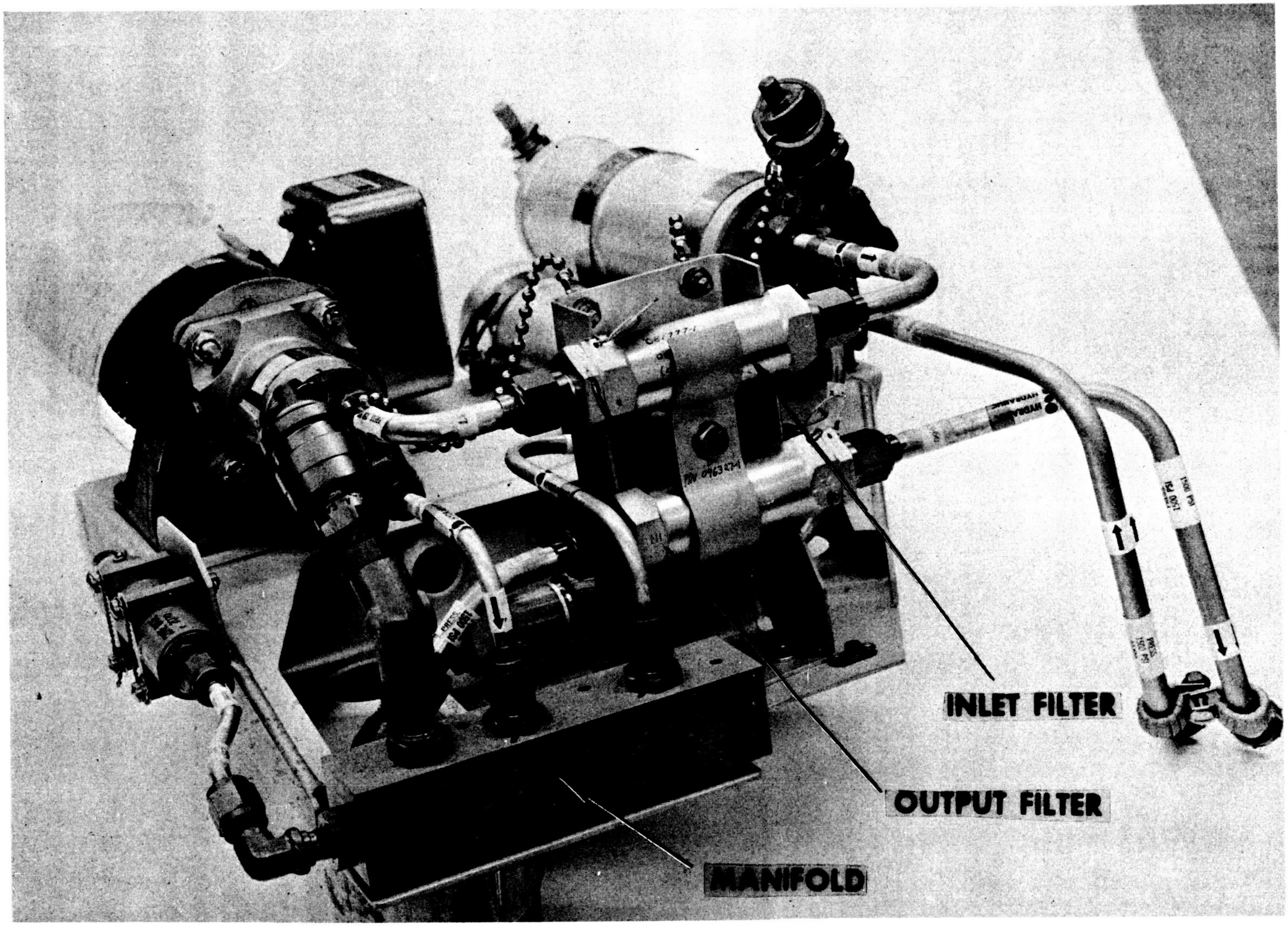
- Fairing internal surfaces coated with sealant

APPENDIX H

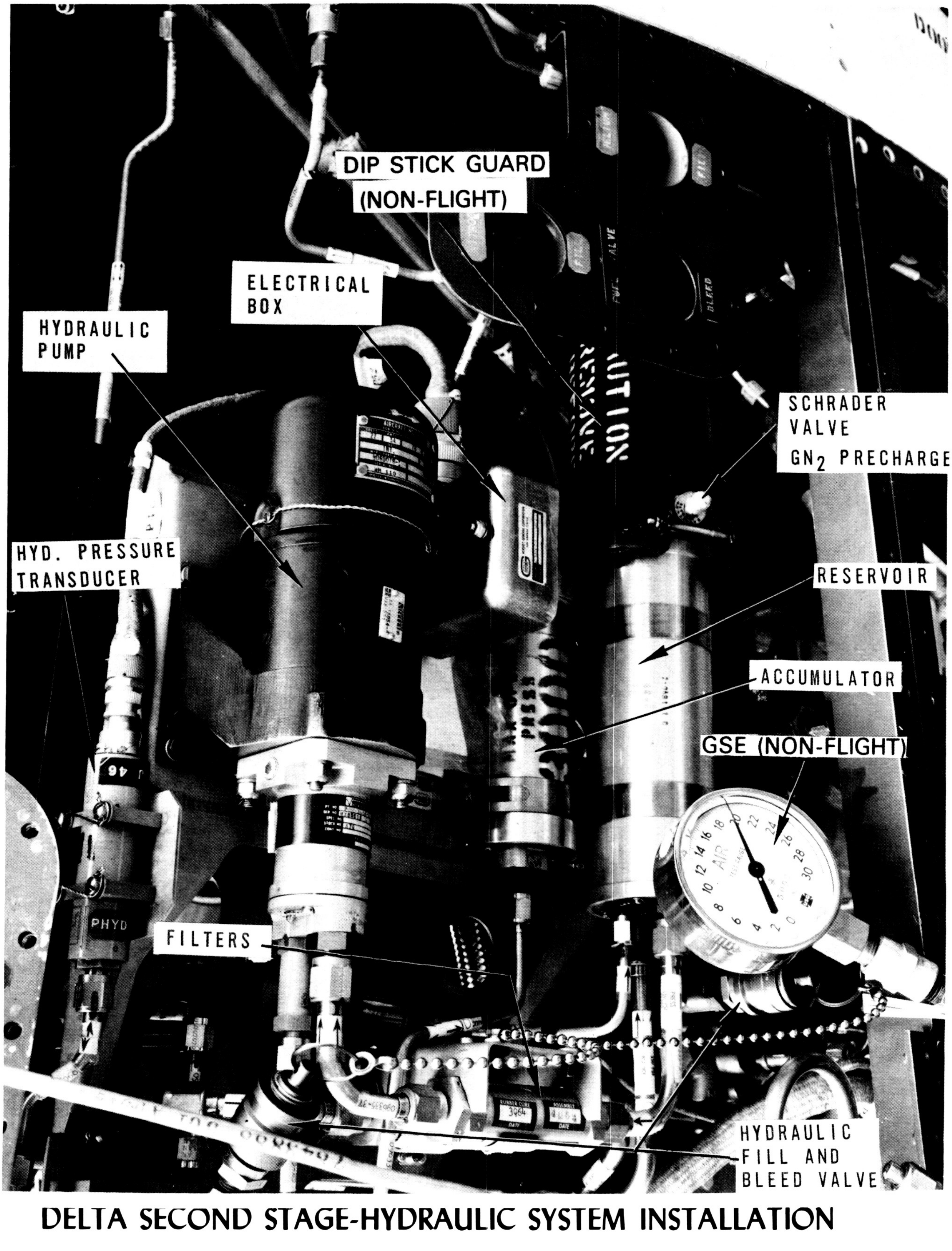
SECOND STAGE HYDRAULIC SYSTEM INSTALLATION



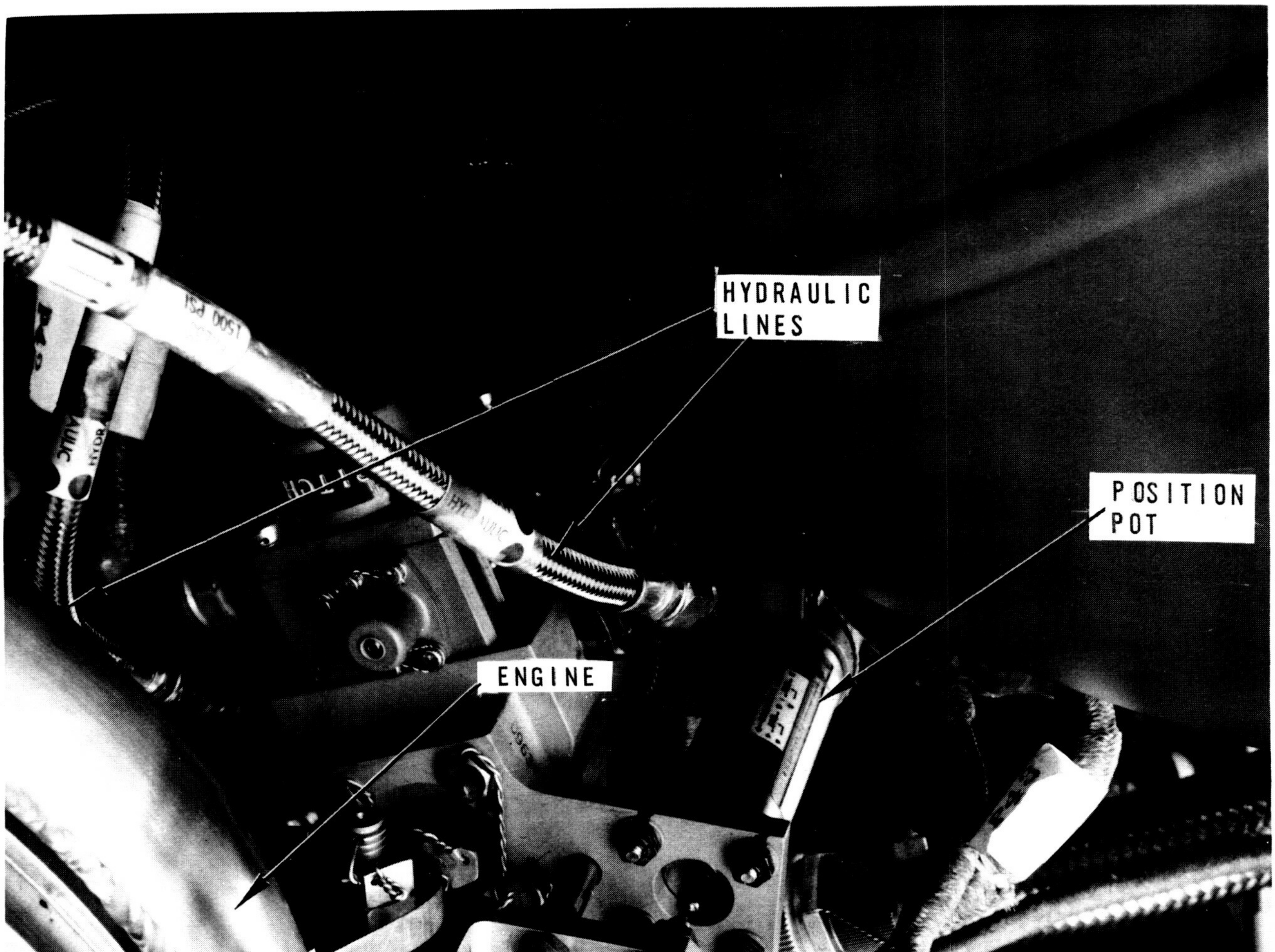
SIDE VIEW-HYDRAULIC SYSTEM SUB-ASSEMBLY



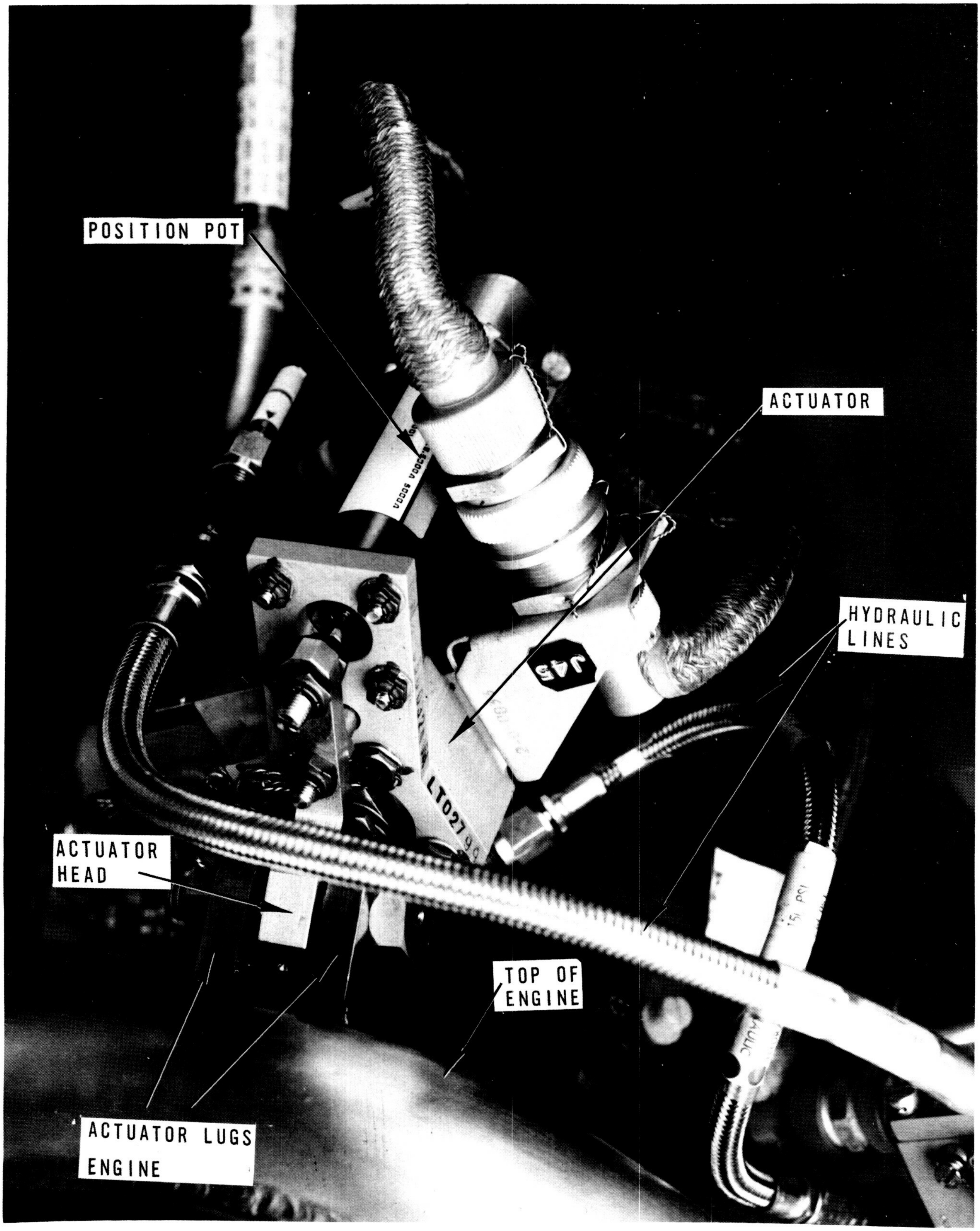
BOTTOM VIEW-HYDRAULIC SYSTEM SUB-ASSEMBLY



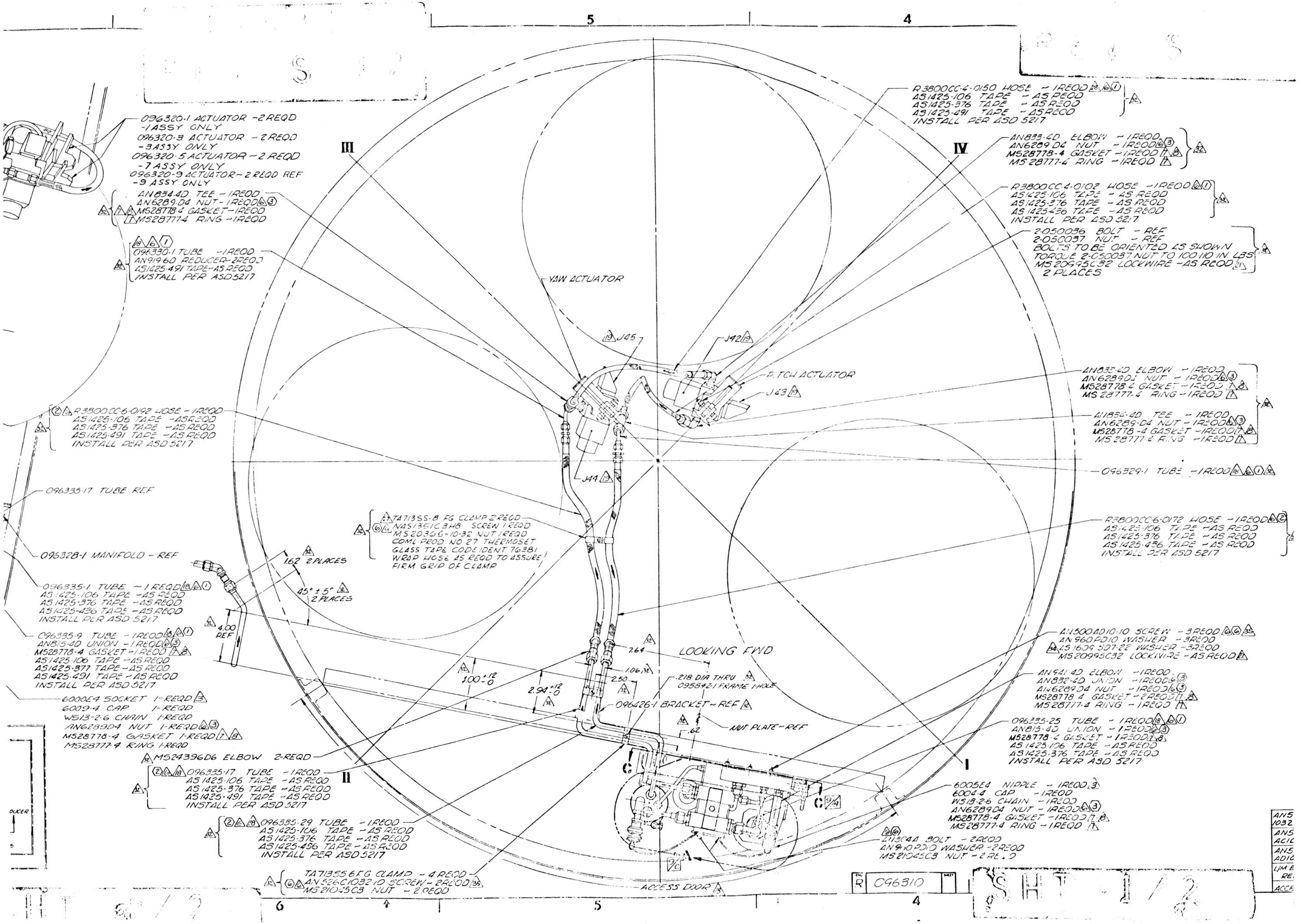
DELTA SECOND STAGE-HYDRAULIC SYSTEM INSTALLATION



VIEW LOOKING UP SHOWING PITCH ACTUATOR INSTALLATION



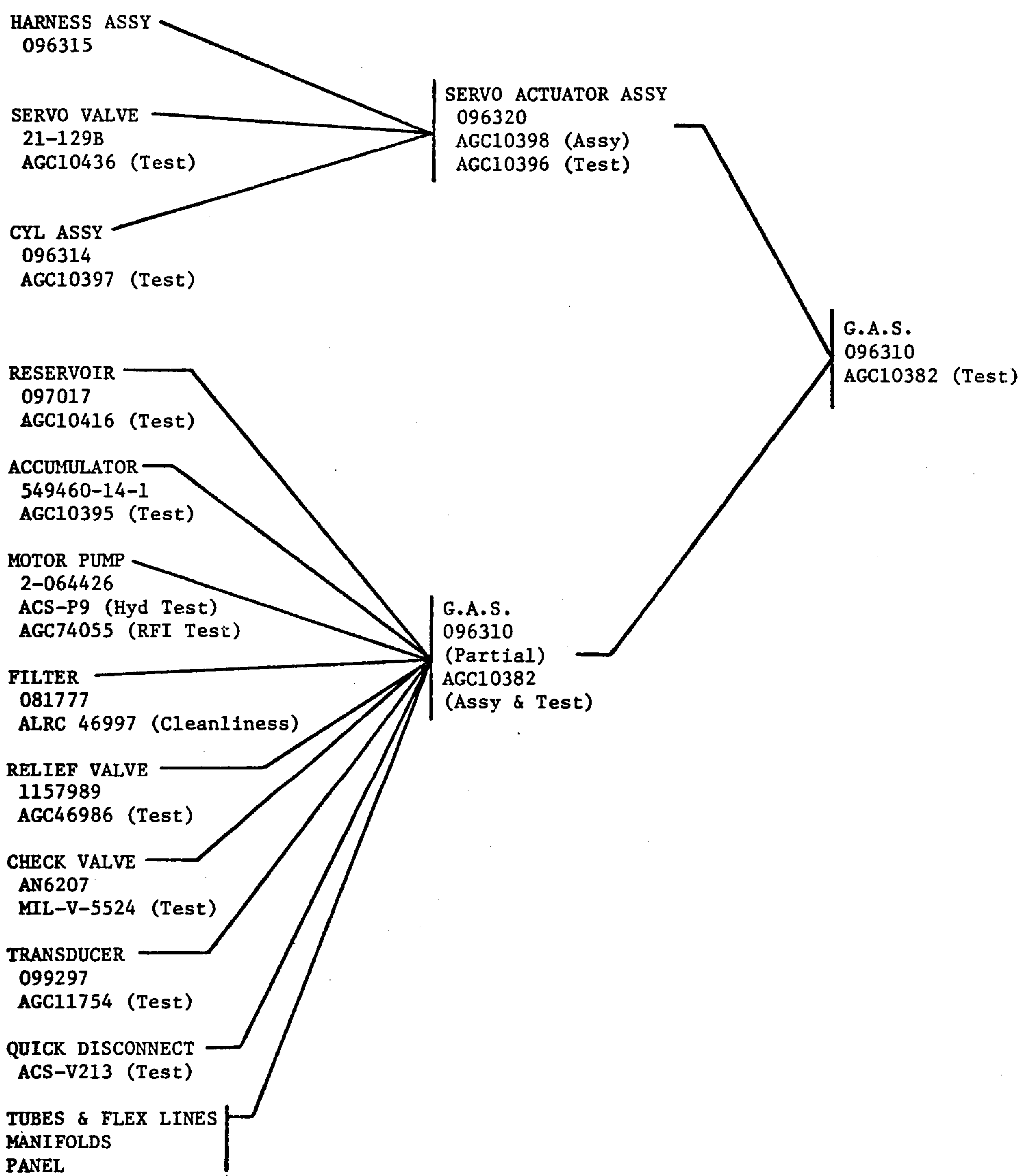
VIEW SHOWING YAW ACTUATOR INSTALLATION



096320-1 ACTUATOR -2 REQD -1 ASSY ONLY
096320-3 ACTUATOR -2 REQD -3 ASSY ONLY
096320-5 ACTUATOR -2 REQD -7 ASSY ONLY
096320-9 ACTUATOR -2 REQD REF -9 ASSY ONLY
AN834-4D TEE -1 REQD
AN6289-D4 NUT -1 REQD
MS28778-4 GASKET -1 REQD
MS28777-4 RING -1 REQD
096330-1 TUBE -1 REQD
AN919-60 REDUCER -2 REQD
AS1425-491 TAPE -AS REQD
INSTALL PER ASD 5217
R3800CC-4-0150 HOSE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-491 TAPE -AS REQD
INSTALL PER ASD 5217
AN833-4D ELBOW -1 REQD
AN6289-D4 NUT -1 REQD
MS28778-4 GASKET -1 REQD
MS28777-4 RING -1 REQD
R3800CC-4-0102 HOSE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-436 TAPE -AS REQD
INSTALL PER ASD 5217
2-050036 BOLT - REF
2-050037 NUT - REF
BOLTS TO BE ORIENTED AS SHOWN
TORQUE 2-050037 NUT TO 100-110 IN. LBS
MS20995C32 LOCKWIRE -AS REQD
2 PLACES
III
IV
YAW ACTUATOR
J45
J42
PITCH ACTUATOR
J43
J44
AN833-4D ELBOW -1 REQD
AN6289D4 NUT -1 REQD
MS28778-4 GASKET -1 REQD
MS28777-4 RING -1 REQD
AN834-4D TEE -1 REQD
AN6289-D4 NUT -1 REQD
MS28778-4 GASKET -1 REQD
MS28777-4 RING -1 REQD
096329-1 TUBE -1 REQD
R3800CC-6-0192 HOSE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-491 TAPE -AS REQD
INSTALL PER ASD 5217
096335-17 TUBE REF
096328-1 MANIFOLD - REF
TA7135S-8 FG CLAMP 2 REQD
NAS1361C3H8 SCREW 1 REQD
MS20365-1032 NUT 1 REQD
COML PROD NO 27 THERMOSET GLASS TAPE CODE IDENT 76381
WRAP HOSE AS REQD TO ASSURE FIRM GRIP OF CLAMP
R3800CC-6-0172 HOSE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-436 TAPE -AS REQD
INSTALL PER ASD 5217
1.62 2 PLACES
45° ± 5° 2 PLACES
4.00 REF
096335-1 TUBE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-436 TAPE -AS REQD
INSTALL PER ASD 5217
096335-9 TUBE -1 REQD
AN815-4D UNION -1 REQD
MS28778-4 GASKET -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-377 TAPE -AS REQD
AS1425-491 TAPE -AS REQD
INSTALL PER ASD 5217
6000E4 SOCKET 1-REQD
6009-4 CAP 1-REQD
WS13-2-6 CHAIN 1-REQD
AN6289D4 NUT 1-REQD
MS28778-4 GASKET 1-REQD
MS28777-4 RING 1-REQD
MS24396D6 ELBOW 2-REQD
096335-17 TUBE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-491 TAPE -AS REQD
INSTALL PER ASD 5217
096335-29 TUBE -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
AS1425-436 TAPE -AS REQD
INSTALL PER ASD 5217
TA7135S-6 FG CLAMP -4 REQD
AN526C1032-10 SCREW -2 REQD
MS21042C3 NUT -2 REQD
1.00 +.12 -0
2.94 +.12 -0
7.64
1.06
2.50
LOOKING FWD
.218 DIA THRU 095842-1 FRAME HOLE
096426-1 BRACKET - REF
.62
NUT PLATE - REF
II
I
C
ACCESS DOOR
AN500AD10-10 SCREW -3 REQD
AN960PD10 WASHER -3 REQD
AS1609-507-22 WASHER -3 REQD
MS20995C32 LOCKWIRE -AS REQD
AN941-4D ELBOW -1 REQD
AN832-4D UNION -1 REQD
AN6289D4 NUT -1 REQD
MS28778-4 GASKET -2 REQD
MS28777-4 RING -1 REQD
096335-25 TUBE -1 REQD
AN815-4D UNION -1 REQD
MS28778-4 GASKET -1 REQD
AS1425-106 TAPE -AS REQD
AS1425-376 TAPE -AS REQD
INSTALL PER ASD 5217
6005E4 NIPPLE -1 REQD
6004-4 CAP -1 REQD
WS18-2-6 CHAIN -1 REQD
AN6289D4 NUT -1 REQD
MS28778-4 GASKET -1 REQD
MS28777-4 RING -1 REQD
AN3C4A BOLT -2 REQD
AN960PD10 WASHER -2 REQD
MS21042C3 NUT -2 REQD
R 096310
SHT 1/2
6
5
4

GIMBAL ACTUATION SYSTEM (G.A.S.)

'E' MODEL FLOW CHART



DRAWINGS AND TEST PROCEDURES APPLICABLE TO DELTA 85, STAGE II, HYDRAULIC SYSTEM. (REF., AEROJET LIQUID ROCKET COMPANY)

APPENDIX I

SPECIAL O-RING INVESTIGATION

A special investigation of the Dip Stick O-ring was made by the Committee to determine its pedigree. Two separate efforts were conducted:

- The End Cap from an old display model reservoir, obtained from KSC, ULO, was dissected to study the details of the Dip Stick Seal design.
- O-rings currently utilized in the Dip Stick Seal (Parker Aircraft Co. number N-304-7) were obtained from ALRC for study.

Display Model Seal

Although this particular seal has no direct bearing on the flight anomaly, several things were learned from extracting the O-ring from the cap, as follows:

1. Inspection of the O-rings revealed abrasion on the top and bottom, but not on the inside diameter (see Figure). This can be attributed to rolling of the O-ring on its seat as the Dip Stick moves through the seal. Since the display model had been exercised untold times in the past without lubrication, this is not surprising. However, it does indicate a mode whereby contamination might be drawn into the seal.

2. Analysis of the design details of the seal reinforced the concept that adequate dip stick seal inspection for so important a seal does not appear feasible with the Delta 85 design.

3. This O-ring was manufactured by Parker with a part number identical to the one currently used. All that is known about the age of this dissected O-ring is that its mold date is prior to May 31, 1967, as evidenced by a blue dot color coding; Parker ceased to color code O-rings of this type (Mil.Spec. #27532 and ANA 438C) as of this date. Spare O-rings received from McDonnell-Douglas were dated 3Q69; these did not have this color code.

4. ANA 438C - An age control document allows the usage of the ring (by the manufacturer) of up to one year after molding and another year for the assembler, so that a total of two years is considered safe (after molding) for usage. For an installed component, three years are allowed from time of assembly to delivery of the vehicle. The age of the Delta 85 reservoir seals should easily meet the ANA 438C age criteria.

5. The accompanying figure shows a definite dimensional difference between the older color coded O-ring and the newer non-coded one. The inside diameter is the same but the outside diameter of the new O-ring is .006 inch larger. However, since the actual age of the color coded O-ring is unknown, the effects of aging which might account for this difference, cannot be determined.

<u>Currently Used (Parker N-304-7) O-ring</u>

The following items were uncovered during the investigation of currently used O-rings:

1. These newer O-rings were covered with a whitish substance that did not appear on the older (color coded) O-ring. Parker representatives indicated that they do not use mold release nor any other coating on the rubber, but that it could be a material "blooming" to the surface.

2. The current N-304-7 O-ring, although compatible with the petroleum based hydraulic fluid (Mil.Spec. H-5606), shows a -38% compression set at 212^{o}F (data from Aerojet General), Parker has suggested their new replacement candidate (N-674-70) is better from the compression set viewpoint (-20% and 212^{o}F).

3. Air permeability for BUNA-N compounds is 4x10^{-8}cc/sec/cm^{2} at 176^{o}F. From the viewpoint of permeability (gas) and compatibility with petroleum based hydraulic fluid, BUNA-N is a very good choice.

4. The O-ring, when "lubricated with hydraulic fluid or oil (Mil.Spec. H-5606), is poor as regards resistance to abrasion. A proper lubrication for this O-ring would be Dupont Krytox 143AZ or equivalent, based on Saturn vehicle experience.

5. An investigation of volatility vs temperature of hydraulic fluid as a lubricant for the O-ring is summarized in the attached Table. A comparison is made of vapor pressure vs temperature for a typical hydraulic oil, Univis J41 (meeting Mil-H-5606 specification requirements), and the inert high temperature lubricant, Krytox 143AZ. At an operating temperature of 180^{o}, frequently reached in the Delta 85 hydraulic system tests, the Mil-H-5606 oil shows a vapor pressure of 4.0 mm Hg. Oil at this temperature exposed to the atmosphere would quickly evaporate. Krytox 143AZ would reflect a 30 to 50 times decrease in vapor pressure over the hydraulic oil. This would result in a much longer lubrication life.

6. Debris was evident on the inside edges of some of the new O-rings, which consisted of flash at the mold parting line.

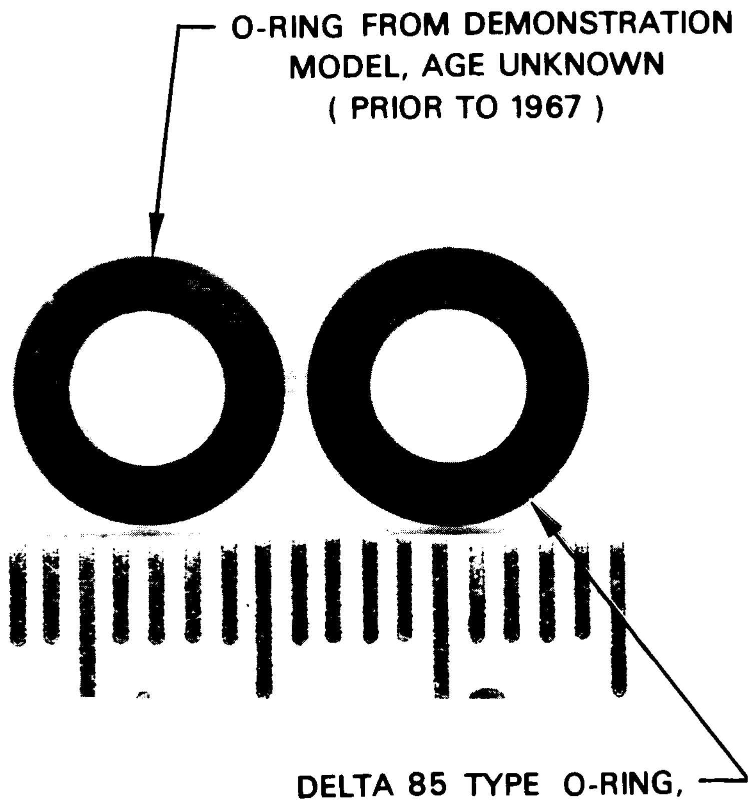
7. According to Parker and Military Handbook #695, BUNA-N compounds are generally resistant to oxidation for a period of 3-5 years.

Conclusions

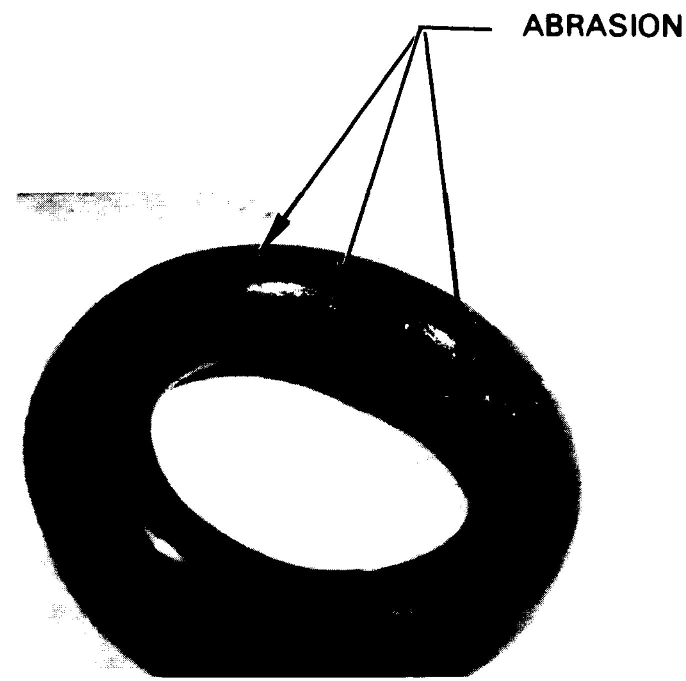
1. Lack of adequate lubrication of the O-ring could have been one of the primary contributing factors in creating the nitrogen leak.

2. Rolling of an O-ring seal in the unlubricated state was verified by wear noted on the O-ring removed from the display model.

3. There is a significant dimensional difference in O.D. (+.006 inch) between the old and current O-ring (see Figure), yet the seal cavity has remained unchanged. This could increase binding and might account for the higher than normal piston friction that was encountered during the reservoir acceptance tests. In the unlubricated state, this could contribute to more rolling of the seal.



VIEW SHOWING APPARENT DIFFERENCES IN SIZE BETWEEN SAMPLES.



VIEW SHOWING ABRASION DUE TO LACK OF LUBRICATION AND ROLLING OF O-RING. (FROM DEMONSTRATION MODEL)

DIP STICK O-RING SEAL, HYDRAULIC RESERVOIR

VAPOR PRESSURE COMPARISON

(Ambient Pressure-One Atmosphere)

Vapor pressure of Univis J-41 (Humble Oil's hydraulic oil product which meets Mil. H-5606 Spec.) vs a high temperature lubricant such as Dupont's Krytox 143A.

	Univis J-41	Krytox 143 AZ
70°F	0.05 mm Hg	0.001 mm Hg
150°F	1.5 mm Hg	0.05 mm Hg
180°F	4.0 mm Hg	0.10 mm Hg
200°F	7.0 mm Hg	0.15 mm Hg

Krytox 143 AZ is a low viscosity Krytox. As viscosity increases the vapor pressure decreases.

Krytox values shown above are not actually measured values but extrapolated from a curve and represent maximum values for Krytox 143 AZ.

APPENDIX J

DELTA 85 FLIGHT READINESS REVIEW

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : John F. Clark
Director

DATE: September 24, 1971

FROM : Herman E. LaGow
Director of Systems Reliability

SUBJECT: Flight Readiness of Delta 85 (OSO-H/TETR)

The only significant problem affecting the flight readiness of the OSO-H launch vehicle (Delta 85) is an apparent EMI effecting the performance of the vehicle Velocity Cut-Off System (VCS). The problem is still being investigated and must remain an open item at this time.

A "plus-time" run of the second stage guidance is made as part of the normal electrical checks of the launch vehicle. The VCS output signal signifying the end of the second burn occurred 5.2 seconds earlier than expected. The test was repeated with the result that the output occurred 4.0 seconds early. The Project has at this point, conducted a large number of tests under varying conditions both on and off the vehicle with the following significant results.

1) The anomaly occurred only when the VCS was mounted in the vehicle; never during bench tests in the laboratory.

2) A second spare VCS exhibited the same problem when installed in the launch vehicle.

3) The VCS behavior is explainable by an anomalous change in state of the flip-flops in the VCS counter, increasing the accumulated velocity count producing an early cut-off signal.

4) While the anomaly is reproducible most of the time, it does not occur every time.

5) Analysis of the resulting cut-off times indicates that the upsetting pulse is received at the VCS at a time, more or less, coincident with the turn-off of the ullage jet solenoid valve.

Subject: Flight Readiness of Delta 85 (OSO-H/TETR)

6) Measurements indicate that noise is present on the input line to the VCS although no time correlation of the noise pulse had yet been made.

7) The anomaly was repeated with the ullage solenoid valve disabled but the operating relays active.

The problem therefore appears to be attributable to noise pulses generated by the collapsing field of the ullage valve relay coils. The problem could then be corrected by installing suppression diodes in the relay coil circuits. I intend to review the data obtained after the Readiness meeting on Thursday (September 23) as well as data obtained after the "fix" is installed and report back to you before Wednesday morning (September 29).

There are several innovations being flown on Delta 85 which bear mention.

POGO FIX--Delta, for the first time is flying a fix to eliminate the POGO oscillation which has been producing the structural loads that have designed many of our spacecraft. The fix consists of an accumulator installed in the liquid oxygen pump inlet line which, when filled with helium in flight, is designed to shift the resonant frequency of the line and thus decouple the propellant system from the vehicle structure. This technique has been successfully used on both Saturn and Titan. The success of its application to Delta depends heavily on the accuracy of the analytical model developed by MDAC on which the specific design is based.

SPINNING OSO SAIL--The OSO sail will be spun-up at the time of shroud separation and will, therefore, be spinning through almost all of the Delta second stage operation. Since OSO is not in its orbital configuration, there exists a slight unbalance in the spinning sail. The unbalance represents no problem during powered flight but would have produced Delta attitude control jet firings during the coast period between first and second burn. Although the controllability of the second stage was not in question, the number of jet firings would have depleted the limited gas supply before the end of the mission. The problem was eliminated by opening up the dead band of the control system to an acceptable one degree. The unbalanced sail also produces a slight increase in tip off rate at spacecraft separation. The OSO project has indicated that the predicted rate of about 2.5 degrees per second is within the control capability of the spacecraft.

Subject: Flight Readiness of Delta 85 (OSO-H/TETR)

RF SHIELD--The front end of the second stage has been enclosed by a newly designed RF shield which physically separates the payload compartment from the rest of the vehicle. Although there has been no pressure test of the diaphragm, there appears to be ample margin in the design to withstand the loads produced by the maximum predicted pressure differential between the payload compartment and the second stage guidance section.

Our Review also covered the malfunction reports and failure analyses generated during vehicle checkout both at the factory and at the range. All have been satisfactorily closed out by the Project.

With adequate assurance that diode suppression of the ullage jet solenoid and relay coils has eliminated the VCS EMI problem, we consider Delta 85 ready for launch.

Edward A. Litkenberg
for Herman E. LaGow

cc:
R. E. Bourdeau
W. R. Schindler

APPENDIX K

SPECIAL TESTS OF HYDRAULIC PRESSURE TRANSDUCER

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : Mr. Alton E. Jones
Assistant Director for Engineering

DATE: Oct. 29, 1971

FROM : Mr. W. A. Russell, Jr., Head
Attitude Control and Stabilization Branch

SUBJECT: CONCLUSIONS OF TESTING OF DELTA PRESSURE TRANSDUCER

From limited tests performed on the Servonics Model 099297-1B 0-2000 PSIG pressure transducer used in the Delta second stage hydraulic system, the following conclusions can be made:

1. The transducer is very stable and linear and has excellent repeatability. My guess from reviewing the data is that the gage resolution (independent of the telemetry system) is about 4 psi.

2. The transducer is apparently temperature compensated. The enclosed data shows a maximum deviation of 12 psi from 72°F to 185°F over 0-1000 psig.

3. The transducer is basically a psig unit, and while it will respond somewhat to lower than atmospheric pressure, it cannot be used with confidence to below about 10 or 12 psia.

My conclusion is that the unit tested is quite acceptable for its application. Possibly a 0-1500 psi unit could be substituted in order to increase the resolution and give better low pressure (50 psig) verification of the reservoir precharge.

William A. Russell, Jr.

cc: Mr. D. Suddeth/Code 763
Mr. R. Drummond/Code 733

Encl. - Memo to Files (John E. Doyle)
"Test of Servonics Pressure Transducer"
dated 10/22/71

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : FILE

DATE: 10/22/71

FROM : John E. Doyle

SUBJECT: TEST OF SERVONICS PRESSURE TRANSDUCER

A Servonics Pressure Transducer, Model 099297-1B, 0-2000 PSIG range, was tested using nitrogen as gas source. The results obtained show that it is a reliable transducer.

A series of four (4) tests were conducted to ascertain the reliability under certain conditions. The first was a calibration test, second and third were voltage ratio vs. PSIG at given temperatures, and the last was to obtain voltage ratio vs. PSIA down to 100 mm Hg. All data collected is presented in graphic or table form attached.

The conclusions arrived at from interpreting the data are, that the transducer is very stable, has good resolution, and when subjected to having a vacuum placed on it, performance still is satisfactory.

John E. Doyle

John E. Doyle

Attachment

TABLE 1

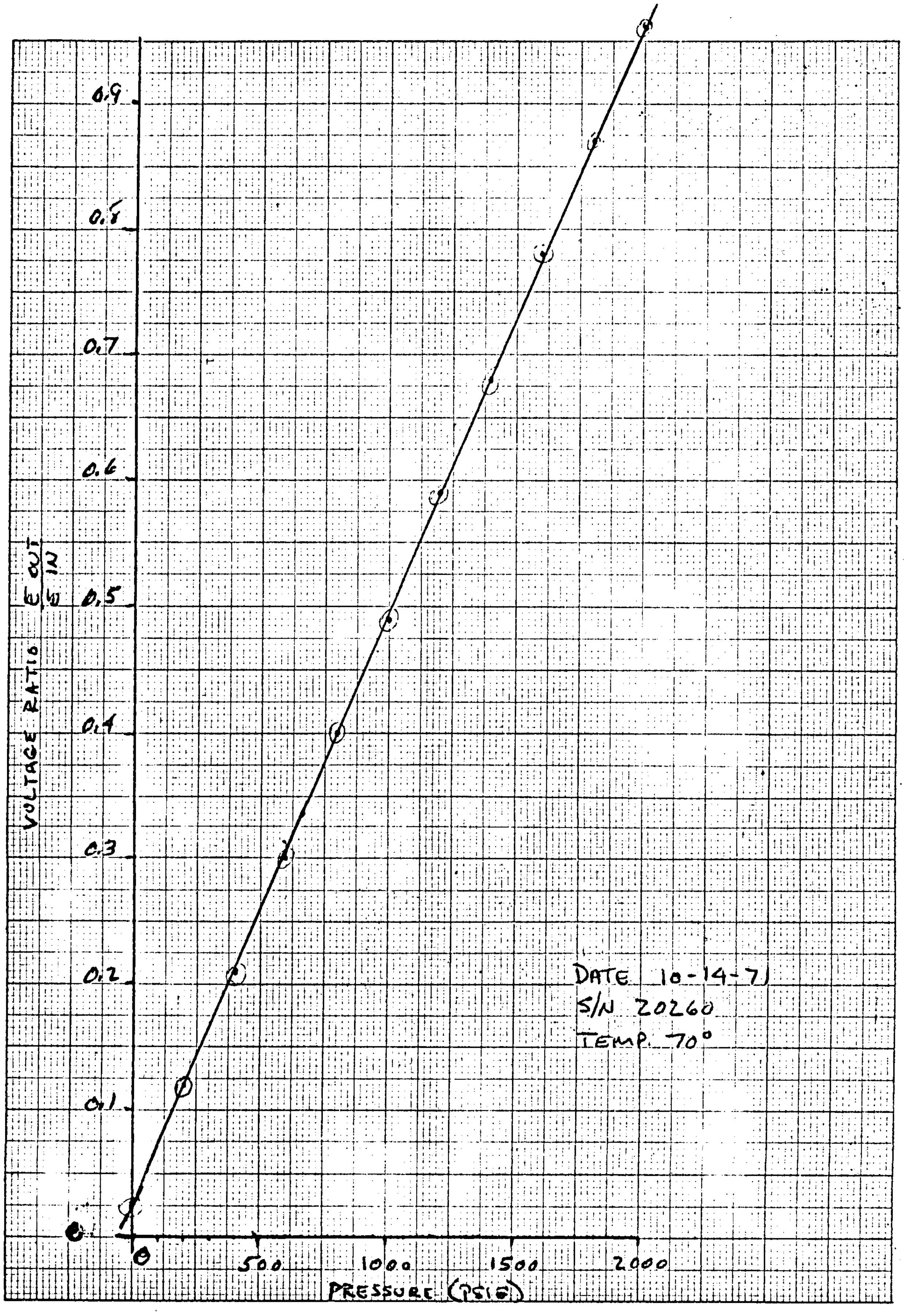
VOLTAGE RATIO READINGS VERSUS PSIA IN MM HG

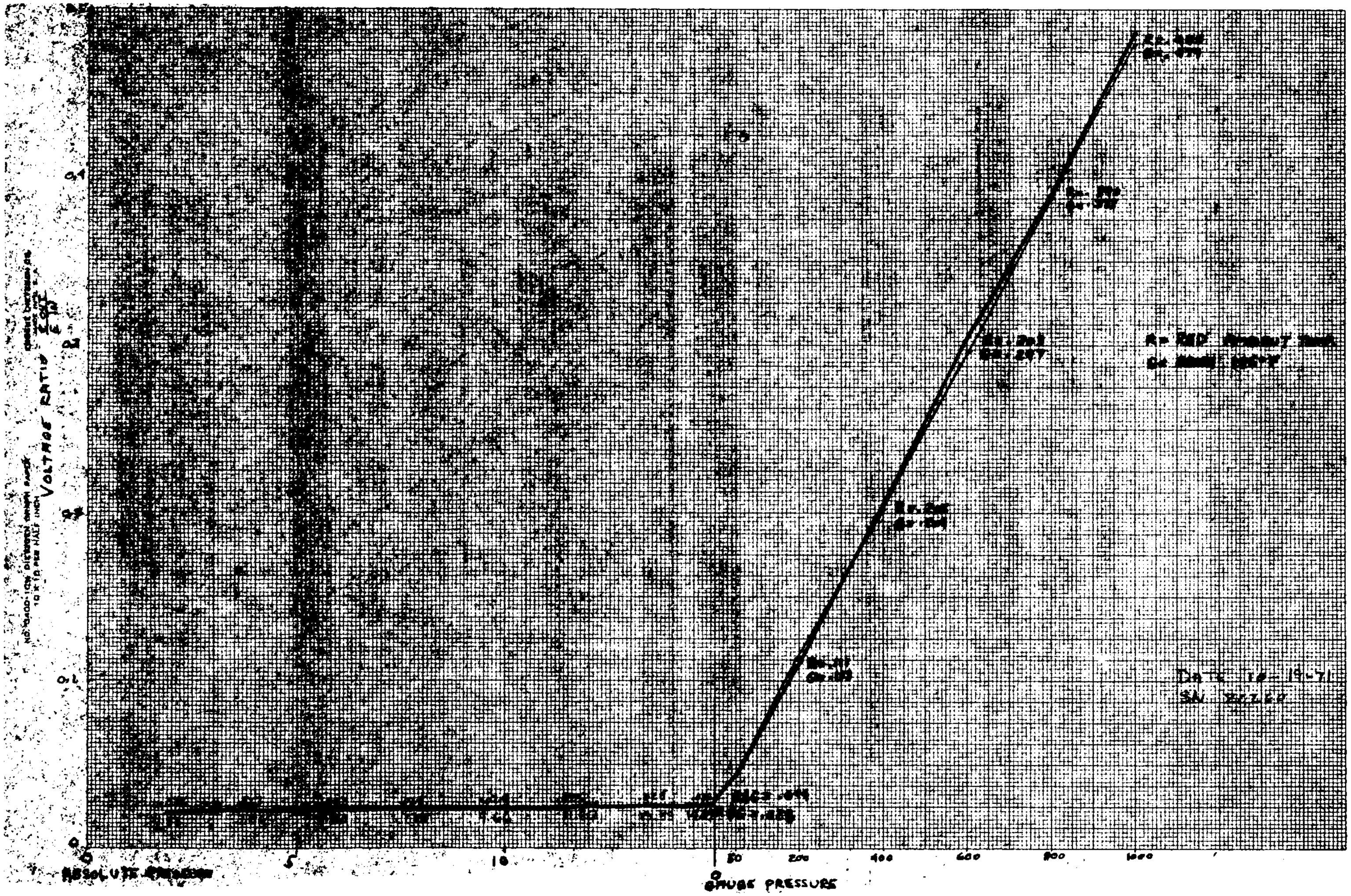
PSIA	VOLTAGE RATIO	
773 mm Hg	.026	Wallace & Tiernan Model FA129 Serial No. FF04874
700 mm Hg	.026	
600 mm Hg	.025	
500 mm Hg	.024	
400 mm Hg	.024	
300 mm Hg	.023	
200 mm Hg	.023	
100 mm Hg	.023	

TABLE 2

VOLTAGE RATIO READINGS VERSUS PSIG

AMBIENT TEMP		185°F	
PSIG	V. RATIO	PSIG	V. RATIO
0	.028	0	.028
50	.044	50	.044
200	.111	200	.113
400	.205	400	.204
600	.303	600	.297
800	.390	800	.388
1000	.485	1000	.479


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
VOLTAGE RATIO E OUT / E IN
0
500
1000
1500
2000
PRESSURE (PSIG)
DATE 10-14-71
S/N 20260
TEMP. 70°



VOLTAGE RATIO
ABSOLUTE PRESSURE
GAUGE PRESSURE
0
5
10
200
400
600
800
1000
0.1
0.2
0.4
DATE 10-19-71

APPENDIX L

SPECIAL TESTS AT ALRC

This appendix was taken from the MDAC draft report titled "Delta 85 Anomaly Report." It is expected that MDAC will re-issue this anomaly report at a later date, however, at this time this is the only written report available describing these tests.

2.2 Test Results

2.2.1 Simulated GN_2 Leak

In attempting to simulate a GN_2 leak, the reservoir GN_2 precharge was first vented to atmosphere. Two test runs were performed in this fashion, and in each case, supply pressure reached normal operating levels as soon as the pump was started.

Subsequently, the GN_2 side of the reservoir was evacuated to 26 inches of Hg. Under this condition, the pump, upon startup, cavitated freely and no external stimuli (manually induced engine motion, etc.) could be introduced to build up any pressure. Testing then proceeded with the intent of determining what the pump threshold was, that is, what pump suction line pressure head was insufficient to prevent pump cavitation. After numerous tests, it was established that the pump would pressurize the system with oil pressure maintained at approximately 11 psia. At somewhat lower pressures, the pump would fail to pressurize the system unless stimulated by some external means, such as manual engine motion, or a shock load applied to the reservoir. Figure II-4 illustrates one of the simulated GN_2 leak tests. The sequence of events is as follows:

a. The reservoir GN_2 pressure was reduced until the pressure at the oil side was 9.6 psia. Under this condition, the pump was turned on and allowed to cavitate freely for 47 seconds (simulating the OSO-H flight).

b. At the conclusion of the 47 seconds the engine was manually slewed. At the time of the slew, a small rise in reservoir oil pressure can be seen.

c. The rise in reservoir oil pressure is then followed by a decay at a rate of approximately 1.6 psia per second. When the oil pressure reached 8.5 psia, pump supply pressure begins to build up very rapidly reaching accumulator precharge (650 psig) in less than one second. The decrease in reservoir oil pressure just prior to supply pressure buildup is indicative that the pump is starting to draw oil out of the reservoir.

d. Subsequent to reaching the accumulator precharge level, the pressure continues building up over a period of 9 1/2 seconds eventually reaching a 1000 psig operating level. Throughout the pressure buildup, the pump is seen to cavitate. Both, long pressure buildup and pump cavitation, are caused by air having been drawn into the pump case past the shaft seal (which is designed to prevent leakage only from the inside out) during the period when the oil pressure was below atmospheric. As the pump begins to pressurize fluid it cavitates as the air passes through each piston. Eventually all the air is removed from the pump and cavitation ceases.

e. At approximately the same time that pressure reaches its operating level, reservoir oil pressure begins to build up eventually reaching 12 psia. This pressure buildup is due to expansion of the air as it passes from the pressure to the return side of the system. When reservoir oil pressure reaches 12 psia the piston breaks loose and the dipstick begins extending thereby indicating the addition of fluid/air volume.

The test closely approximates the data seen during the OSO-H second burn. The only difference noted is the relatively slow pressure buildup. This characteristic can be eliminated by operating the pump within a vacuum chamber thereby preventing the introduction of air into the pump case. Also, such a simulation would more closely recreate the condition prevalent on OSO-H. An attempt was made to establish this condition but it proved unsuccessful in that a vacuum could not be maintained. No further attempts were made as the cause of the slow pressure buildup is readily explainable.

2.2.2 Simulated Oil Leak

Figure II-5 illustrates the conditions monitored during one of the simulated oil leak tests. In this case, approximately 300 cubic centimeters of oil were drained from the system prior to the test. Removal of this amount of oil was just sufficient to cause the reservoir piston to bottom-out on the oil side thereby recreating a condition simulating loss of reservoir precharge. Following was the sequence of events during the test.

a. Prior to pump turn on, reservoir oil pressure was 15 psia.

b. When the pump was turned on, reservoir oil pressure dropped very rapidly to approximately 4.5 psia indicating that oil was being drawn from the return side to the pump.

c. Approximately 1 1/2 seconds after pump turn on, system pressure reached the accumulator precharge level of 650 psig. Thereafter, the pump maintained a mean pressure of 750 psig, but under a constant cavitating mode. Peak to peak pressure excursions exceeded 100 psig.

d. During pump operation, reservoir oil pressure was maintained at approximately 6.7 psia.

e. At pump turn off, the system bled down within a time period consistant with the maximum pressure reached during the test run.

The simulated leak test established that the pump would start pressurizing the system immediately upon turn on and that system pressure, with no oil in the reservoir, would not go beyond 750 psig. There was, therefore, no correlation between the simulated oil leak test and the actual conditions experienced during the OSO-H Flight.

2.2.3 Stuck Reservoir Piston

The stuck reservoir piston test attempted to simulate a condition where the system pressure decayed during the coast phase due to failure of the piston to follow the oil level as it contracted. During performance of the test, extreme difficulty was experienced in attempting to restrain the reservoir piston even though, as noted above, the test unit did not have the strengthening shoulder as did the flight unit. Eventually the piston was restrained by applying a compressive load with a C-clamp placed on the reservoir barrel as well as by reducing the GN_2 precharge to approximately 30 psig. Figure II-6 illustrates test data obtained during this test. The sequence of events was as follows:

a. The system was operated until the fluid temperature reached 202° F. At that time it was turned off and allowed to cool. When the temperature reached 151° F the reservoir piston was clamped in a fixed position. The system was then allowed to cool further until the reservoir oil pressure indicated approximately 10 psia.

b. The pump was then turned on and operated for 47 seconds. At pump startup reservoir oil pressure dropped suddenly to nearly 3 psia and then increased rapidly back to 9 psia, thus indicating that the pump was drawing a vacuum on the suction line. System pressure, however, failed to rise.

c. At the completion of the 47 seconds, the engine was slewed manually causing a reservoir oil pressure spike. Immediately thereafter system pressure came up to the accumulator precharge level and then proceeded on to 1000 psig in approximately 7 seconds. The slow buildup from accumulator precharge level to operating level was again caused by introduction of air into the pump case drain (as was evident during the GN_2 leak test). Throughout operation the pump cavitated producing pressure variations approximating 100 psig peak to peak.

d. System bleeddown was normal.

The stuck reservoir test produced data similar to that seen on OSO-H, thereby making this failure mode a possible candidate. The difficulty experience while trying to bind the reservoir piston, however, is significant in that it is very unlikely that such a condition would occur in flight. This is particularly true because the reservoir flown on OSO-H was of the newer configuration (with a reinforcing shoulder on the barrel) making it even more difficult to apply the necessary compressive load.

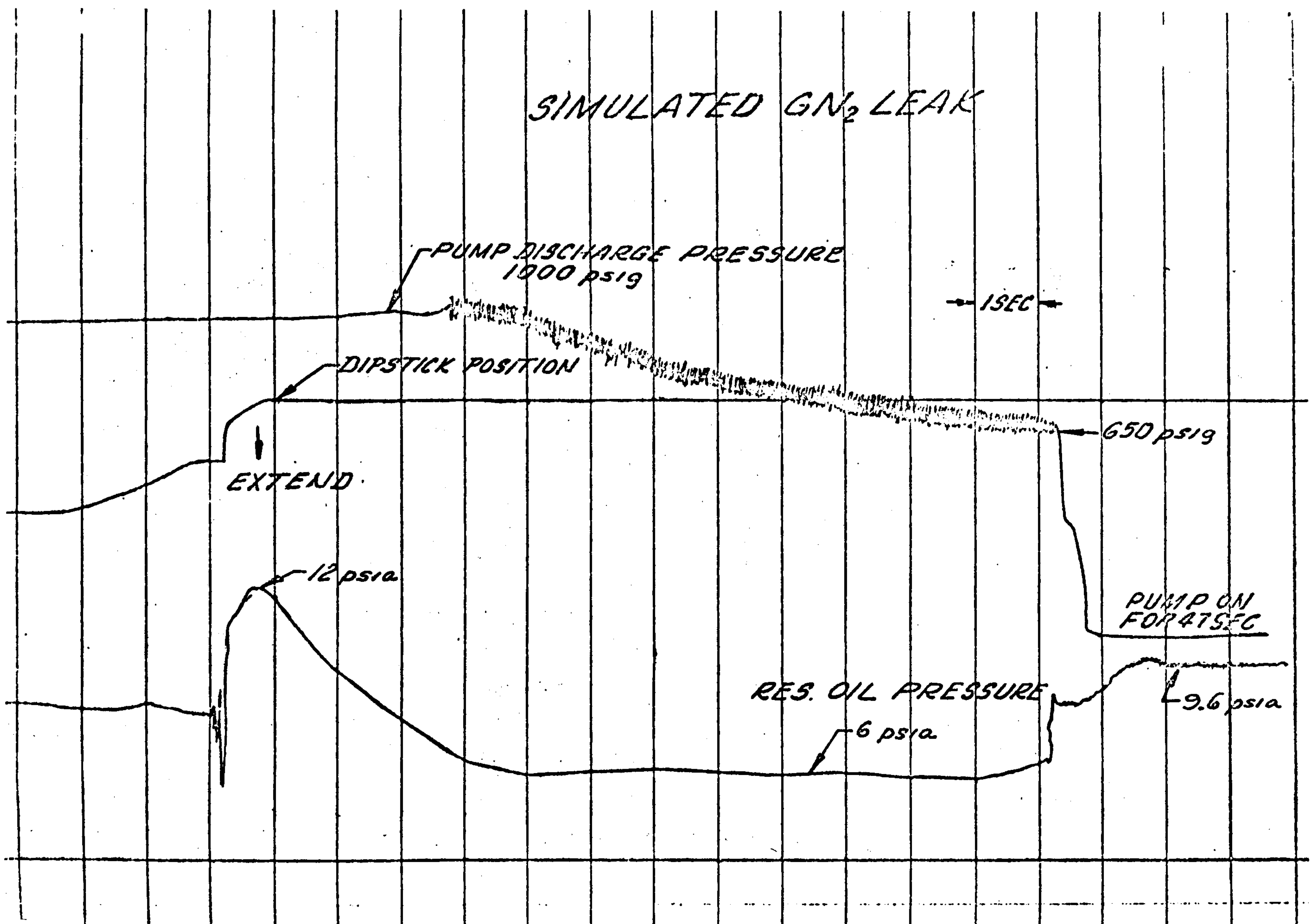

SIMULATED GN_2 LEAK
PUMP DISCHARGE PRESSURE
1000 psig
DIPSTICK POSITION
EXTEND
12 psia
1 SEC
650 psig
PUMP ON
FOR 47 SEC
RES. OIL PRESSURE
6 psia
9.6 psia

FIGURE II-4

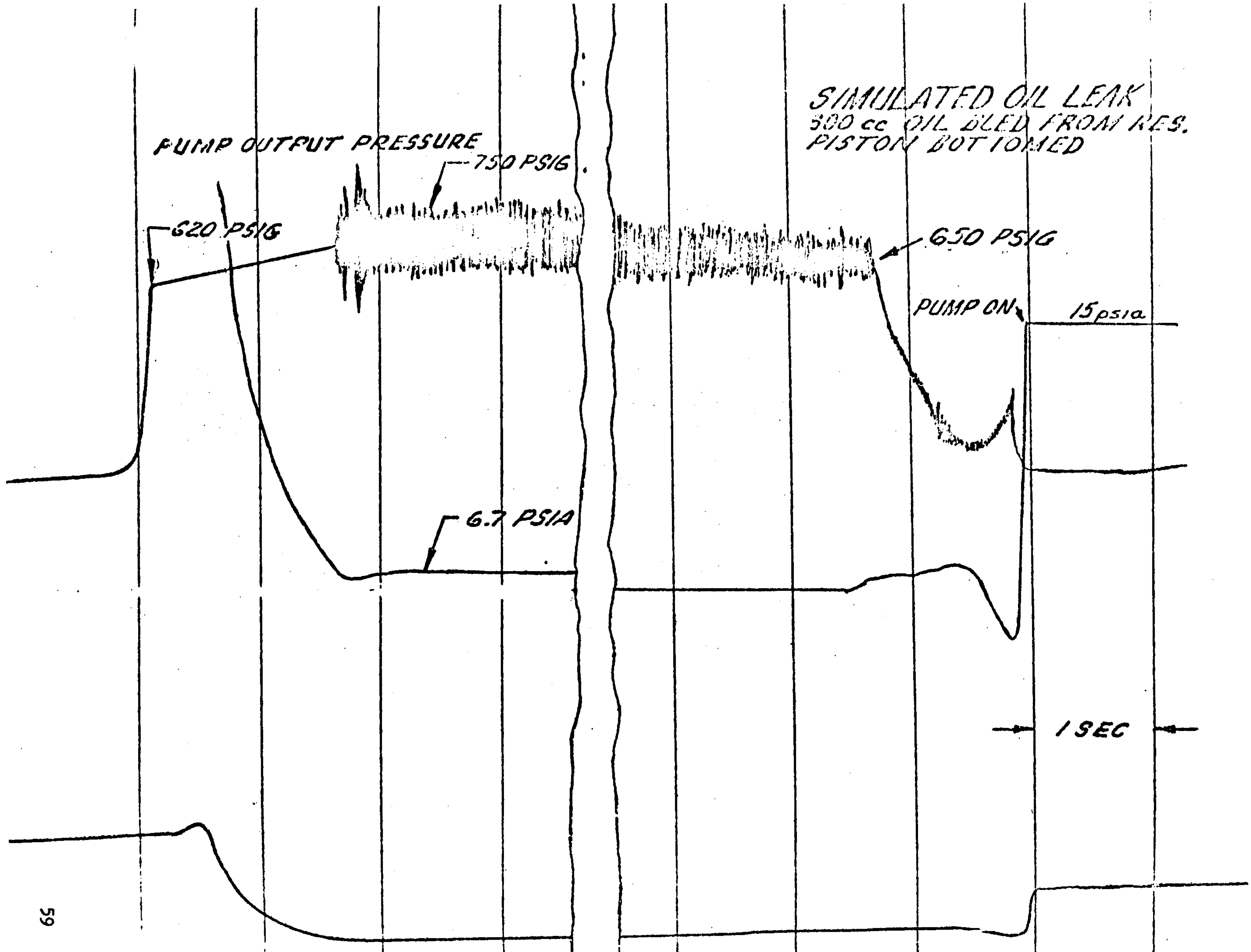

SIMULATED OIL LEAK
300 cc OIL BLED FROM RES.
PISTON BOTTOMED
PUMP OUTPUT PRESSURE
750 PSIG
620 PSIG
650 PSIG
PUMP ON
15 psia
6.7 PSIA
1 SEC

FIGURE II-5

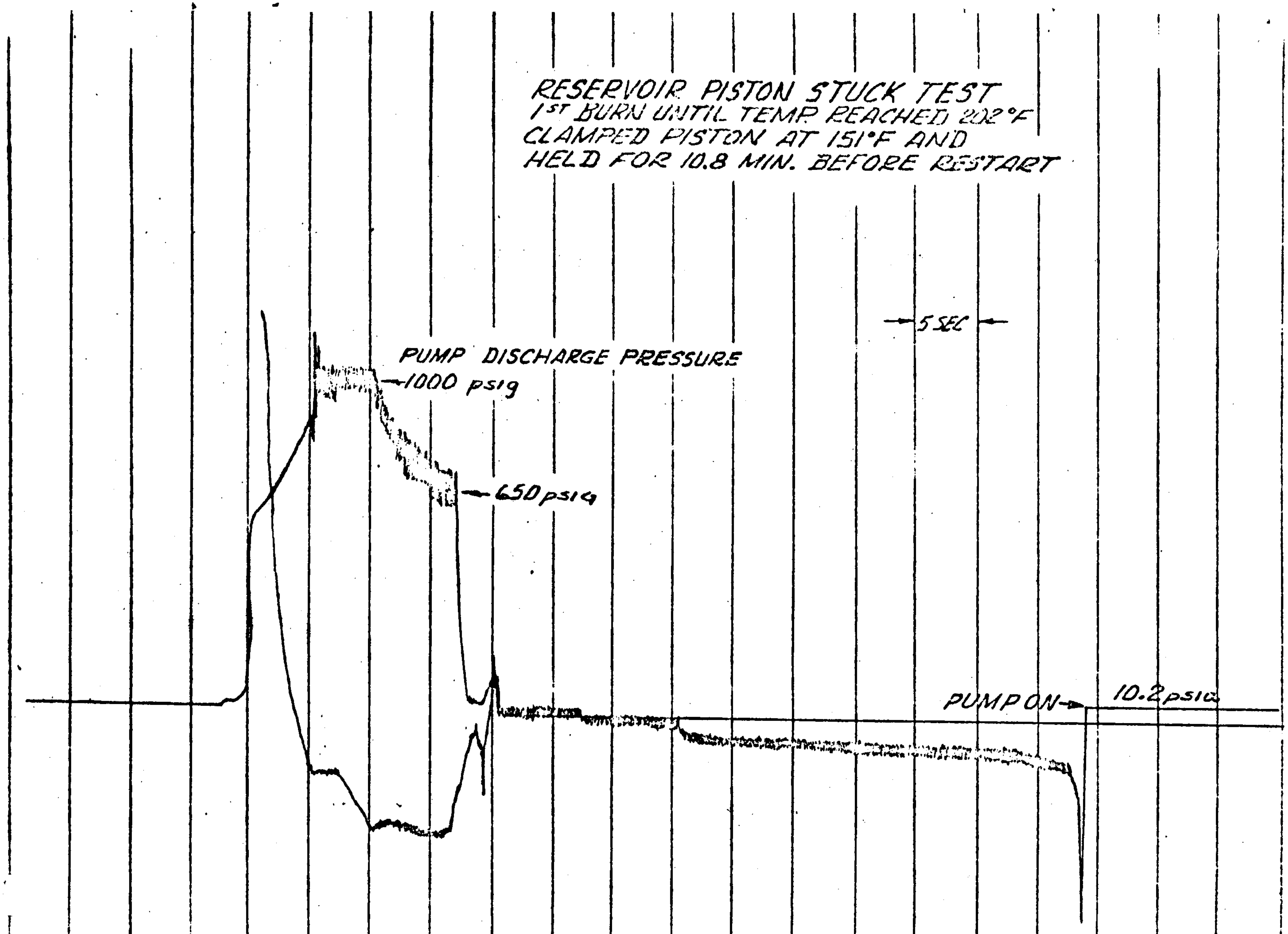

RESERVOIR PISTON STUCK TEST
1ST BURN UNTIL TEMP. REACHED 202°F
CLAMPED PISTON AT 151°F AND
HELD FOR 10.8 MIN. BEFORE RESTART
5 SEC
PUMP DISCHARGE PRESSURE
1000 psig
650 psig
PUMP ON
10.2 psia

FIGURE II-6

TABLE II-3

OSO-H ANOMALY TEST SUMMARY

Test With "F" Model Actuator (-9) in Simulator

Date	Run #1	Type of Test	Reservoir Pressure GN_2	Oil	Pump Discharge Pressure	Remarks
9/29/71	1	Vented Reservoir	Atmospheric		1070	Pump: 27 volts 31 amps
9/29/71	2	Vented Reservoir	Atmospheric		1060	Pump: 26 volts 31.5 amps
9/29/71	3	Vacuum	26" Hg		Cavitated	
9/29/71	4	Vacuum	13" Hg		1020	Pump very noisy
9/29/71	5	Vacuum	15" Hg		1020	Pump: 26 volts 30 amps
9/29/71	6	Vacuum	20" Hg		1000	Pump: 26 volts 31 amps
9/29/71	7	Vacuum	25.5" Hg		1000	
9/29/71	8	Vacuum	27" Hg		1010	Suspect air in oil side
9/29/71	9	Vacuum	27" Hg 22" Hg 3" Hg 27" Hg	18" Hg 15" Hg 11" Hg 18" Hg	Cavitated Cavitated 1010 1000	System Refilled and rebled after run
9/29/71	10	Vacuum	14" Hg 3" Hg	25" Hg 10" Hg	0 1000	Pump: 26 volts 12 amps
9/29/71	11	Vacuum	20" Hg	12" Hg	1000	Pump: 26 volts 31 amps
9/29/71	12	Vacuum	21.5" Hg	14" Hg	1000	Pump: 26 volts 31 amps
9/29/71	13	Vacuum	24" Hg	17" Hg	0 0	Pump: 26 volts 15.5 amps Manually slewed engine
9/29/71	14	Vacuum	23" Hg	15" Hg	0 0	Pump: 26 volts 14.6 amps Manually slewed engine

OSO-H ANOMALY TEST ... MARY (Continued) TABLE II-4 (CONT)

Date	Run Number	Type of Test	Conditions	Pump Discharge	Remarks
10/2/71	18	Time Based Stuck piston	1st burn 12.9 @ 202° F clamped @ 3.2 min. 151° F held for 10.8 min. GN_2 pressure @ 20 psig	0	Cavitated for 47 seconds.
				Full	cut TC restraint switch signal to negative. TC started move to center, Pump started
10/2/71	19	Time Based Stuck piston	Temperature to 202° F. Temp. dropped to 145° F after pump off clamped piston at pump off + 3.2 min.		
			held for 10.8 min.	0	Pump cavitated for 47 seconds.
			released TC and switched command from + to -	Full	Total run 63 seconds
10/2/71	20	Temperature Based stuck piston	Temperature to 180° F Shut down clamp piston restart at 160° F	1000 psia	Moved thermacouple from manifold to reservoir. Pump started off

TABLE II-4 (CONT)

OSO-H ANOMALY TEST S IARY (Continued)

Date	Run Number	Type of Test	Conditions	Pump Discharge	Remarks
10/1/71	8	Temperature Based - 115° F	oil side @ 9.0 psia		dipstick fully extended. air in system
10/1/71	9	Temperature Based - 115° F	oil side @ 9.0 psia	Full	Upon impace of the reservoir
10/1/71	10	Temperature Based 1st burn to 115° F	oil side @ 10 psia yaw servo H/O right	0	
			TC tied to " "	Full	at 47 sec cavitation cut thrust chamber (TC) Restrain. TC started moving to center flipped command to negative, pump fired.
10/1/71	11	Temperature Based 1st burn to 115° F	oil side @ 10 psia yaw servo H/O right	0	
			TC tied to " "	Full	Pump started @ 47 sec of cavitation
10/2/71	12-14	No test			Omitted
	15	oil leak simulation	Reservoir piston bottomed (drained 300cc oil)	700 psig	ran for 16 seconds (31 volts & 27 amps)
			2nd start	730 psig	ran for 7 seconds
10/2/71	16	oil leak simulation	fill & bleed after run #15. Drained 300cc oil	750 psig	
10/2/71	17	temperature Based stuck piston	1st burn 180° F coast to 171° F clamp piston restart @ 150° F	Full	piston moved clamp did not hold
			reclamped	Full	pump started clamp held

TABLE II-4

OSO-H ANOMALY TEST SUMMARY

Test with Model "E" Actuator (-5) in Simulator

Date	Run Number	Type of Test	Conditions	Pump Discharge	Remarks
9/30/71	2	Temperature Based - 115° F First Burn	Restart and Run for 59 sec	Full	120° F @ end 1st Run 80° F @ end 10 min. complete 99° F @ end 59 sec
9/30/71	3	Threshold - Vacuum	28" Hg	0	
9/30/71	4	Threshold - Vacuum			oil side transducer failed to operate
9/30/71	4a	Threshold - Vacuum	oil side 11.3 psia	0	replaced transducer after impacting reservoir
9/30/71	4b	Threshold - Vacuum	oil side 11.3 psia	0	manually gimbaled engine
				1000	after impacting reservoir
10/1/71	5	Temperature Based - 115° F	oil side 11.3 psia Yaw servo H/O right engine tied @ H/O right	Full	Pump fired @ restart
10/1/71	6	Temperature Based - 115° F	oil side @ 11 psia oil side @ 10.5 psia oil side @ 7.5 psia	Full Full 0	Pump fired @ restart Pump fired @ restart
10/1/71	7	Temperature Based - 115° F	servo spool off null (-0.5 ma) oil side 8.0 psia	0 Full	 Pump started after impacting reservoir

APPENDIX - M

RELATED DATA:

1. OSO-H Checkout History
2. Hydraulic System History

This appendix was taken from the MDAC draft report titled "Delta 85 Anomaly Report." It is expected that MDAC will reissue this anomaly report at a later date, however, at this time this is the only written report available describing this material.

1. OSO-H Checkout History

The following is a summation of the checkout activities associated with the OSO-H second stage hydraulic system.

1.A. Component Testing at ALRC

Component production acceptance testing is the responsibility of ALRC. Following is pertinent PAT component data.

Reservoir (S/N 56)	-	Receiving inspection 10/12/69 - no discrepancies Acceptance test data a) weight 1.45 lb b) fluid cleanliness acceptance c) proof test to 500 ± 25 psig acceptable d) packing friction differential (extend and retract) = 22 psi e) no gas or oil leakage f) assembly date 4Q69
Motor Pump (S/N 49)	-	RFI and functional tests acceptable
Accumulator (S/N 69V0145)	-	Receiving inspection 4/13/69 Acceptance test data a) proof and leak check gas and oil side; acceptable b) packing friction: 10 psi @ 1050 psig

1.A. (Continued)

Actuators -
(S/N's 123 and 124

Acceptance test includes

a) Rod assembly setting

b) Potentiometer adjustment

c) Proof test

d) Leak test

e) Continuity test

f) Open loop rates test

g) Vibration test

h) Dielectric test

i) Static calibration

j) Frequency response

Discrepancy: potentiometer out of adjustment

1.B. <u>Assembly Buildup and Test - ALRC</u>

Assembly and checkout of the vehicle hydraulic system is the responsibility of ALRC.

1. Received at ALRC on 3/16/70

2. HPRV was replaced with new P/N unit

3. Acceptance test dipstick readings

    0 psig = 4.11"
    50 psig = 4.11"
    pump on = 3.26"

4. Tubes 096335 -9, -17, -25 and -33 replaced due to not meeting ovality requirements.

5. Final fill and bleed dipstick readings.

    0 psig = 4.11"
    50 psig = 4.23"
    pump on = 3.18"

1.C. Checkout ACtivities - MDAC/SMMCO

The vehicle was received at MDAC on 9/3/70. Following are significant events noted:

1. Modification

   a) ALRC installed filters replaced with MDAC cleaned units.

   b) Air fill valves on accumulator and reservoir were lockwired.

2. Component Rejections

   a) 4 FARRS on 4 tube assemblies for nicks and scratches on the flare surfaces. Flares were polished and accepted.

   b) FARR 502-015-816 suspected filter contamination resulted in replacing the filters.

3. Tests

   a) 1B16655 - Hydraulic system fill and bleed.
      Discrepancy: at completion, excessive air present in system. Procedure was executed again with results satisfactory.

   b) 1B19018 - Guidance and control system checkout. Actuator centering and slew checks acceptable.

   c) 1D08077 - Duel composite checks operation of all vehicle systems.
      Discrepancy: Erratic output of transducer noted at pump turnon. Condition acceptable because meaningful data was still obtained.

1.D. Checkout Activities - MDAC/FTC

1. 1B90083 - During pre-VOS checkout (vehicle horizontal) the following discrepancies were noted.

1. D. 1. (Continued)

a) Yaw actuator did not appear to align properly on its bearings.

b) Flex hose was found to chafe an electrical harness. Both items were acceptable with the vehicle in a vertical attitude.

2. 1B19387 - The following items were checked on the hydraulic system:

a) Torque stripes

b) Remove seepage drain plug from hydraulic pump

c) Pressurize the accumulator

d) Pressurize the reservoir and check system for air content.

e) Check reservoir dipstick for proper level.

f) Install protective cover over the motor.

g) Inspect tube sleeves for cracks.

The following system measurements were recorded:

a) Reservoir precharge at 4.015 inch dipstick: 52 psig

b) Accumulator precharge: 665 psig

c) Dipstick length with reservoir gas volume unpressurized: 4.031 inches.

During checkout oil was noted at a yaw actuator return line coupling nut. The coupling nut was checked for proper torque and found acceptable. No leakage was noted and the oil was considered to have been residual from previous component replacement activities.

3. 1B20227 - During the second stage qualification test the hydraulic system operation was normal.

4. 1B20229 - Second stage control system checks were performed and system performance was acceptable.

5. During the prelaunch activities numerous electrical tests were performed which required the operation of the hydraulic system.

   a) Total pump starts - 120

   b) Total pump operating time - 8 hours, 30 minutes

   c) The 20 minute maximum pump run time was slightly exceeded 5 times during checkout. The maximum operating time experienced was 23.2 minutes.

   d) Again as at SMMCO, a pressure trace dropout was noted. A review indicated the same problem as recorded in SMMCO. Condition was acceptable.

   e) A summary of hydraulic pressure data points is presented in Table II-5. These values were recorded during the many hydraulic system operations during checkout at FTC. Examination of the data reveals normal operation, with no significant trends of any kind.

2. Hydraulic System History

2.1 Configuration

The second stage hydraulic system has flown on a total of 126 missions (including Able, Ablestar and Delta Programs) without undergoing major changes. Prior to the above programs, the system was also utilized on Vangard series vehicles. Data for the latter missions is not available for review.

The system presently installed on DSV-3E type vehicles is defined by ALRC Drawing 096310. Three configurations of this installation have been flown.

a. Installation P/N 096310-1 was utilized on three DSV-3E missions. This configuration included P/N 096320-1 actuators (old style servo valve) and a P/N 097017-1 Reservoir (without strengthening shoulder on barrel).

b. Installation P/N 097310-3 was flown on 20 Delta vehicles. This configuration differed from the -1 only from the standpoint that the servo actuators had been frequency response tested in a vertical attitude.

c. Installation P/N 096310-7 (which was the configuration flown on OSO-H) had previously flown 21 times. This configuration included the P/N 097017-3 Reservoir (with strengthening shoulder on barrel), a specially tested and identified high pressure relief valve (P/N 1157-989-1) and P/N 096320-5 servo actuators which included a modified servo valve to preclude wetting of the torque motor coil cavity.

Other major components installed on the -7 configuration system include:

P/N 549460-14-1	Reservoir
P/N 2-064426-2	Motor Pump
P/N 081777-1	Filters (2)
P/N 099297-1	Transducer

2.2 Qualification Tests

During development of the Improved Delta Vehicle (DSV-3E-3) a study was conducted to determine what qualification testing had been accomplished on various components. The results of this study are listed below. (It is to be noted that at the time of development of the DSV-3E-3 Vehicle, a component qualification program was not considered necessary because the components had already been proven flight worthy by numerous successful flights.)

A. Hydraulic Accumulator, P/N Bendix 549460-14-1

1. Similar Component: Accumulator, Bendix 549460-14-1 (Ablestart, Able, Delta & Vangard)

2. Drawing Review: Identical components. Detail drawings not available as these are vendor part numbers.

3. Test Review: a. Component Test (AGC-1580)
   Salt Spray: 50 hours at 95°F per MIL-E-5272B
   No corrosion.

   b. System Test: Able, Ablestar, Delta and Vangard

4. Evaluation: Accumulator is acceptable for flight based upon previous flight experience.

B. Hydraulic Reservoir, P/N 097017-1

1. Similar Component: Hydraulic Reservoir, 2-068160 (Ablestar)

2. Drawing Review: The Ablestar Reservoir P/N 2-050662 was replaced by P/N 2-068160 to simplify manufacturing, to increase the supply pressure and to increase the strength of the assembly. P/N 2-068160 has since been re-identified as P/N 1112010-1. Drawing 1112010 was not available for review but presumably is identical to Improved Delta P/N 097017-1.

3. Test Review: a. Component tested for Ablestar (SGC R235-860-5)

   Proof Test - 500 psi (10 times)
   Cycling test - 1001 cycles 4" stroke
   Gas Leakage - no leakage after 25,200 cycles of endurance test
   Fluid Leakage - No leakage after 25,200 cycles of endurance test
   Functional - 16 psi maximum differential pressure to cycle.
   Burst Test - 1200 psi - no failure.
   Storage under pressure - no leakage in 18 days.
   Humidity
   Salt spray
   Vibration - 5-20 cps .4 in double amp.
   21-100 cps 8.0g RMS
   100-2000 cps 8.0g RMS .1g^2/cps
   Endurance cycling - 25,200 cycles

   b. System Tests: Flight Tests: Ablestar

4. Evaluation: Reservoir is flight acceptable based upon component test results and Ablestar flight experience.

C. Filter, 081777-1

1. Similar Component: Filter, 081777-1 (Delta)

2. Drawing Review: Identical to Delta component

3. Test Review: a. Component Tests: No test results available.

   b. System Tests: Flight Tests: Delta

4. Evaluation: Filter is flight acceptable based upon previous flight experience.

D. Check Valve, AN6207-4

1. Similar Component: Check Valve, AN6207-4 (Ablestar, Vangard, Delta & Able)

2. Drawing Review: AN parts. Drawing not reviewed. Identical parts used on Ablestar, Vangard, Delta and Able.

3. Test Review: a. Component Tests: Component not tested but presumed to meet MIL spec. requirements which meet or exceed Improved Delta requirements.

   b. System Tests: Flight Tests: Able, Ablestar, Delta and Vangard.

4. Evaluation: Valve is flight acceptable by virtue of conformance to MIL Specifications, previous flight experience.

E. Servo Valve, Moog 21-129

1. Similar Component: Servo Valve, Moog21-129 (Ablestar)

2. Drawing Review: Parts are identical

3. Test Review: a. Component Qualification with Servo Adapter. (AGC-1580)

   Humidity: 10 days, 95% relative humidity, 24 hour temperature cycle 60-160°F. No corrosion.

   Salt Spray: 50 hours at 95°F per MIL-E-5272B. Screws corroded.

   Vibration: 3 axes, 0-2000 cps, $0.2g^2$/cps, operated satisfactorily against 200# load, 1000 psig inlet pressure, 20°F.

   b. System Tests: Flight Tests: Able, Ablestar, Delta & Vangard.

4. Evaluation: Valve is flight acceptable based upon Able component qualification and previous flight experience.

F. Potentiometer, P/N Bourns 2001408001

1. Similar Component: Potentiometer, P/N Bourns 2001405001 (Ablestar)

2. Drawing Review: Potentiometer nearly identical to that used on Ablestar. Minor mechanical differences such as: 1/4" threaded end on Improved Delta version rather than 10-32 threaded shaft for Ablestar.

3. Test Review: a. Component Qualification for Ablestar (Space General) S-5432-01-12)

Shaft seal friction: 0.29 lbs average, 0.41# maximum.
Noise: Acceptable level.
Vibration: 6 g RMS, 20 to 2000 cps, 15 minutes
Dynamic: Hysteresis .16 ma, no back lash
Life Cycle: 100,000 cycles 600 cycles at 1 cps
1200 cycles at 2 cps
23200 cycles at 10 cps
Repeated 4 times at amplitude of $\pm$ 1/2° at 1 cps.
Acid Spray: No contamination problem in windings.

b. System Tests: Flight Tests: Ablestar (Similar component)

4. Evaluation: Potentiometer is flight acceptable based upon component qualification which meets Improved Delta requirements, and previous flight experience.

G. Quick Disconnect, P/N Wiggins 6000E4

1. Similar Component: Quick Disconnect, P/N Wiggins 6000E4, (Ablestar, Vangard, Able, Delta)

2. Drawing Review: Parts are identical

3. Test Review: a. Component Qualification for Able (AGC-1580)

Humidity: 10 days, 95% relative humidity, 24 hour temperature cycle 60-160°F. No corrosion.

Salt Spray: 50 hours at 95°F per MIL-E-5272B. No corrosion.

Vibration: 5 minutes each axis 0-2000 cps, $0.2g^2$/cps No leak at 1050 psig during vibration.

b. System Tests: Flight Tests: Able, Ablestar, Delta and Vangard.

4. Evaluation: Component is flight acceptable based upon component qualification for Able which meets or exceeds Improved Delta requirements, and previous flight experience.

H. Hydraulic Motor-pump, P/N 2-064426-2

1. Similar Component: Hydraulic Motor-pump, 2-062226-2 (Ablestar) (Vickers AA-19054A)

2. Drawing Review: Parts are identical.

3. Test Review: a. Component tested successfully as follows:

Voltage 25-29 vdc
Current 35 amps (maximum)
Duty cycle - 16 minutes "full load", 60 minutes "off"
Operating pressure 1000 psi
Flow - .8 gpm (min. at 1000 psi)
Oil temp. - + 30°F to +225°F.
Inlet pressure 14 psia to 60 psia - satisfactory operation
Acceleration - 10 g's - satisfactory operation
Vibration - 10 to 2000 cps and return in 60 seconds at 6 g's. (Repeat 10 times)
NOTE: Test was conducted as follows:
10-60-10 cps (20 seconds)
60-500-60 cps (26 seconds)
500-2000-500 cps (14 seconds)
(Repeated 10 times)
Temperature - ambient +30°F to 120°F
oil +30°F to 225°F
Altitude - S.L. to 200,000 ft.
Humidity - 0 to 100%
Shock - 30 g's in 11 ms (non-operating), repeat 3 times after which it operates satisfactorily.
Salt, fungus, etc.
Endurance test - total operating time - 100 hours
NOTE: Unit operated continuously for 32 minutes during altitude test.
In addition to the above test, Aerojet conducted an evaluation test on a P/N 2-064426-2 motor pump (Repeat 4077-09, Sept. 1965) to verify satisfactory operation at 32 vdc for two minutes followed by 13 minutes of operation at 29 vdc. All requirements were met, with no apparent degradation of motor-pump performance after repeated runs.

b. System Tests: Flight Test: Ablestar

4. Evaluation: The motor-pump is flight acceptable based upon the component testing and previous flight experience.

I. Hydraulic Actuator, P/N 096312-1

1. Similar Component: Hydraulic Actuator, 2-050027 (Ablestar & Delta)

2. Drawing Review: Improved Delta component is nearly identical to Ablestar and Delta. Improved Delta cylinder requirements are more severe.

3. Test Review: a. Component Qualification with servo valve (AGC-1580)

   Humidity: 10 days, 95% relative humidity, 24 hour temperature cycle 60-160°F, Actuator bolts corroded.

   Salt Spray: 50 hours at 95°F per MIL-E-5272B. Additional corrosion noted, but did not affect function.

   Vibration: 3 axes, 0-2000 cps, $0.2g^2$/cps. Actuator functioned normally gainst 200 lb. load with 1000 psig inlet pressure.

   b. System Tests: Flight Tests: Ablestar and Delta.

4. Evaluation: Actuator is flight acceptable based upon component tests and previous flight experience.

2.2 Cont.

Subsequent to the failure of Delta 73, Pioneer E, the second stage high pressure relief valve was replaced with a reconfigured unit which included pinned adjustment nuts, a closely controlled probe to poppet diametral clearance, and high temperature/shock qualification tests.

Testing of the valve is documented in ALRC Report 9900:160. The conditions during these tests included stability at temperatures in excess of 250°F. Cycle response was also checked at elevated temperatures, and the test operations met or exceeded the expected flight thermal environment as recorded on the BIOS-B flight. Although the temperature history is not included in the referenced ALRC report, a temperature history plot is available at MDAC from one of the tests. In that particular case, a temperature rise of 107°F was experienced over a 1200 second run time without instability. This temperature rise is similar to what would have been expected during the OSO-H flight.